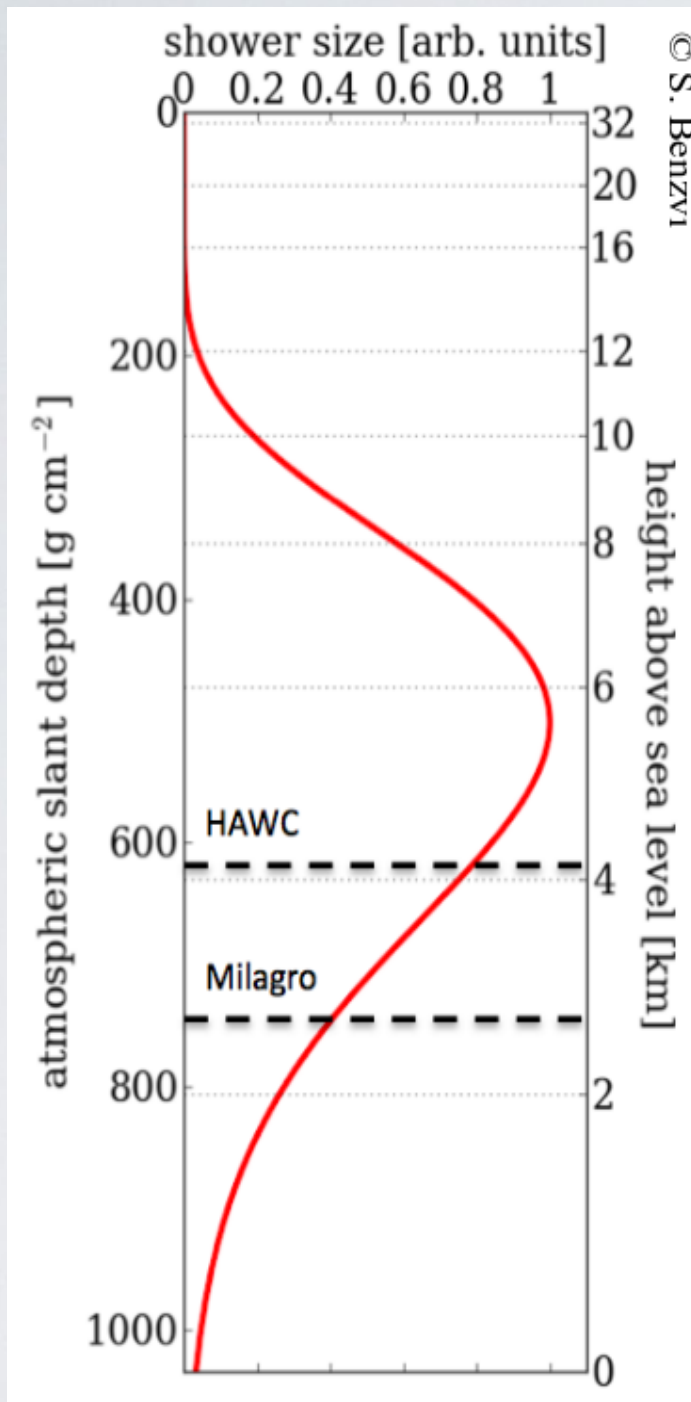


Gamma-ray astronomy across 6 decades of energy: synergy between Fermi, IACTs, and HAWC

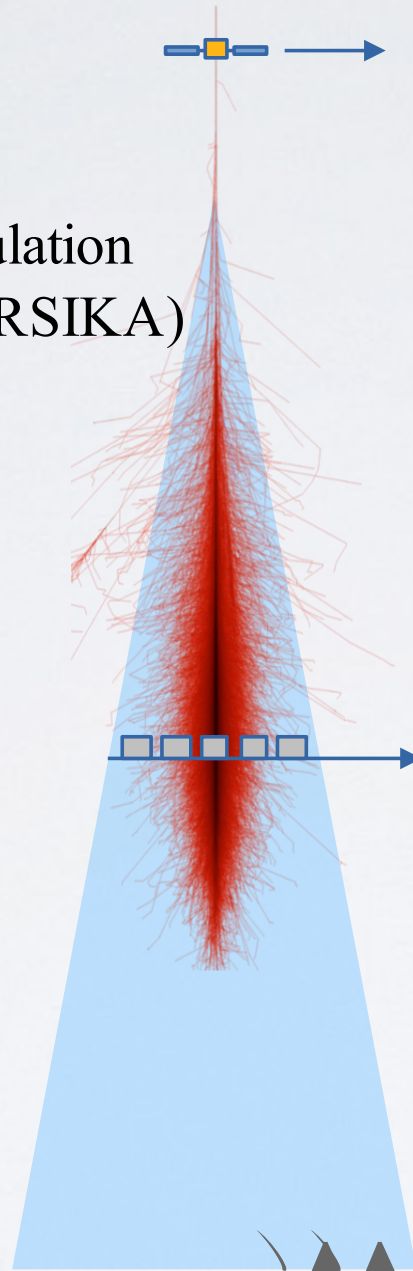


C. Michelle Hui, NASA/MSFC
7th International Fermi Symposium
Oct 18, 2017

Gamma-Ray Observatories



Simulation
(CORSIKA)



Wide Field of View,
Continuous
Operations

Satellite Detector



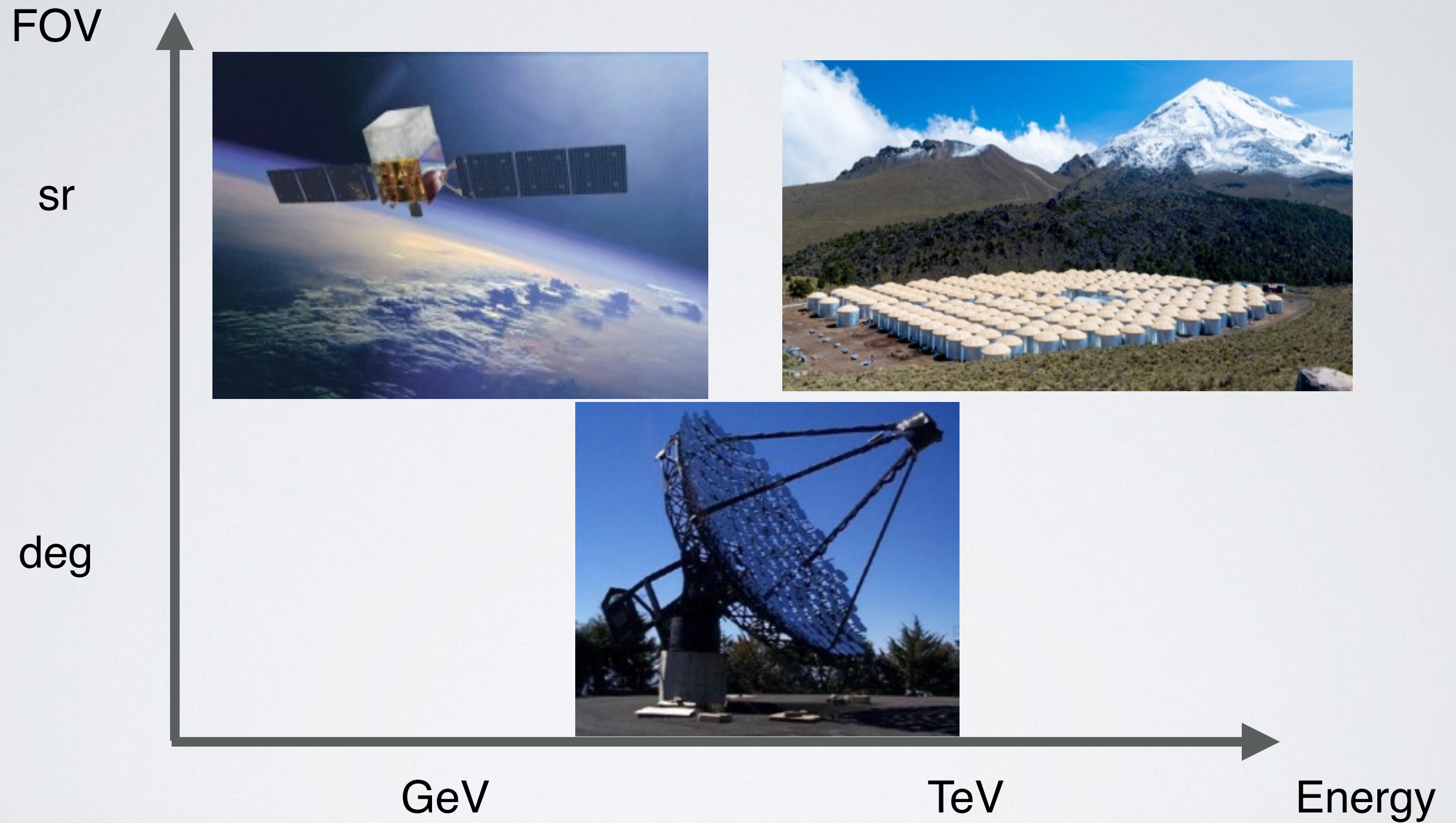
**Extensive Air Shower
(EAS) Detector**



TeV Sensitivity

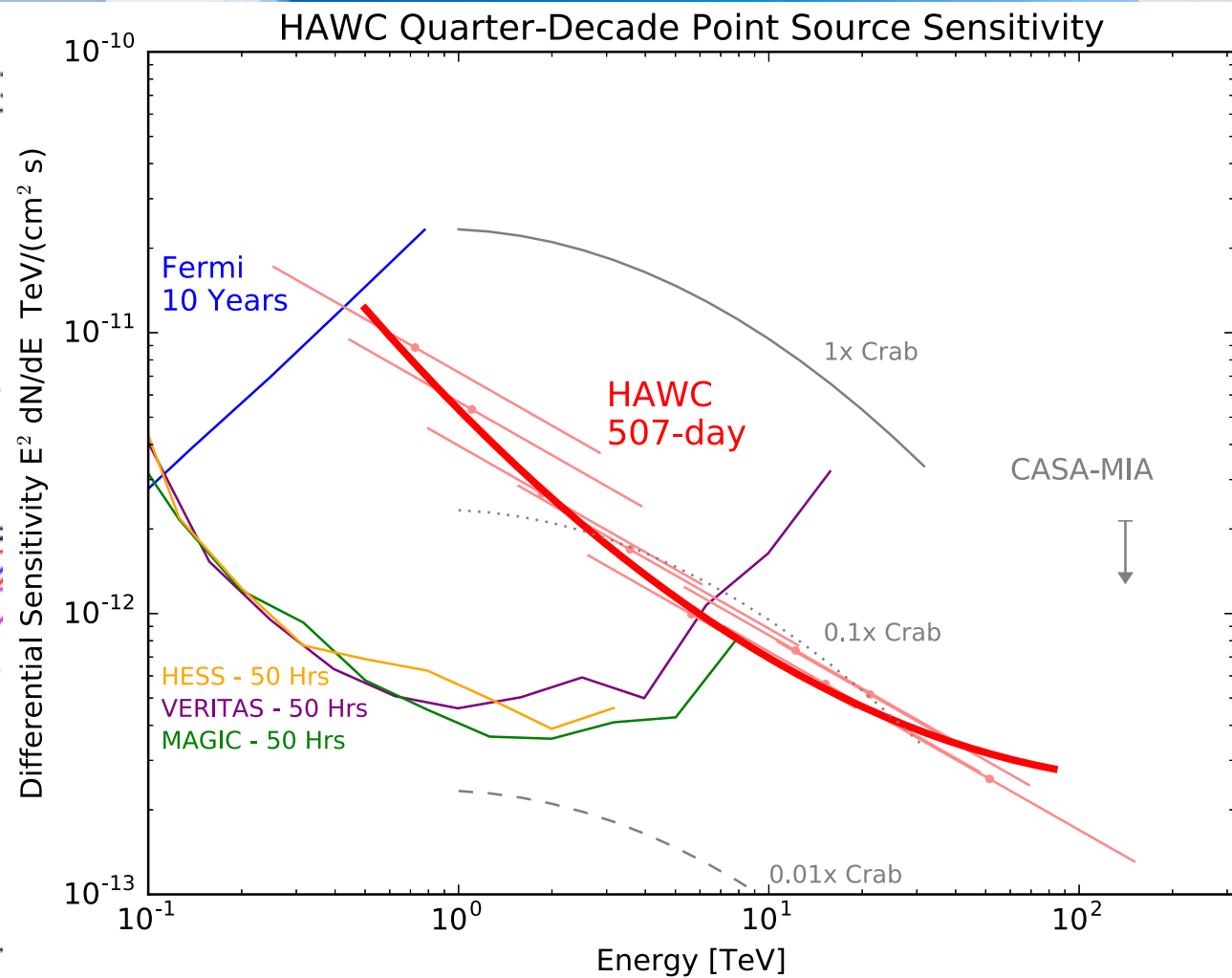
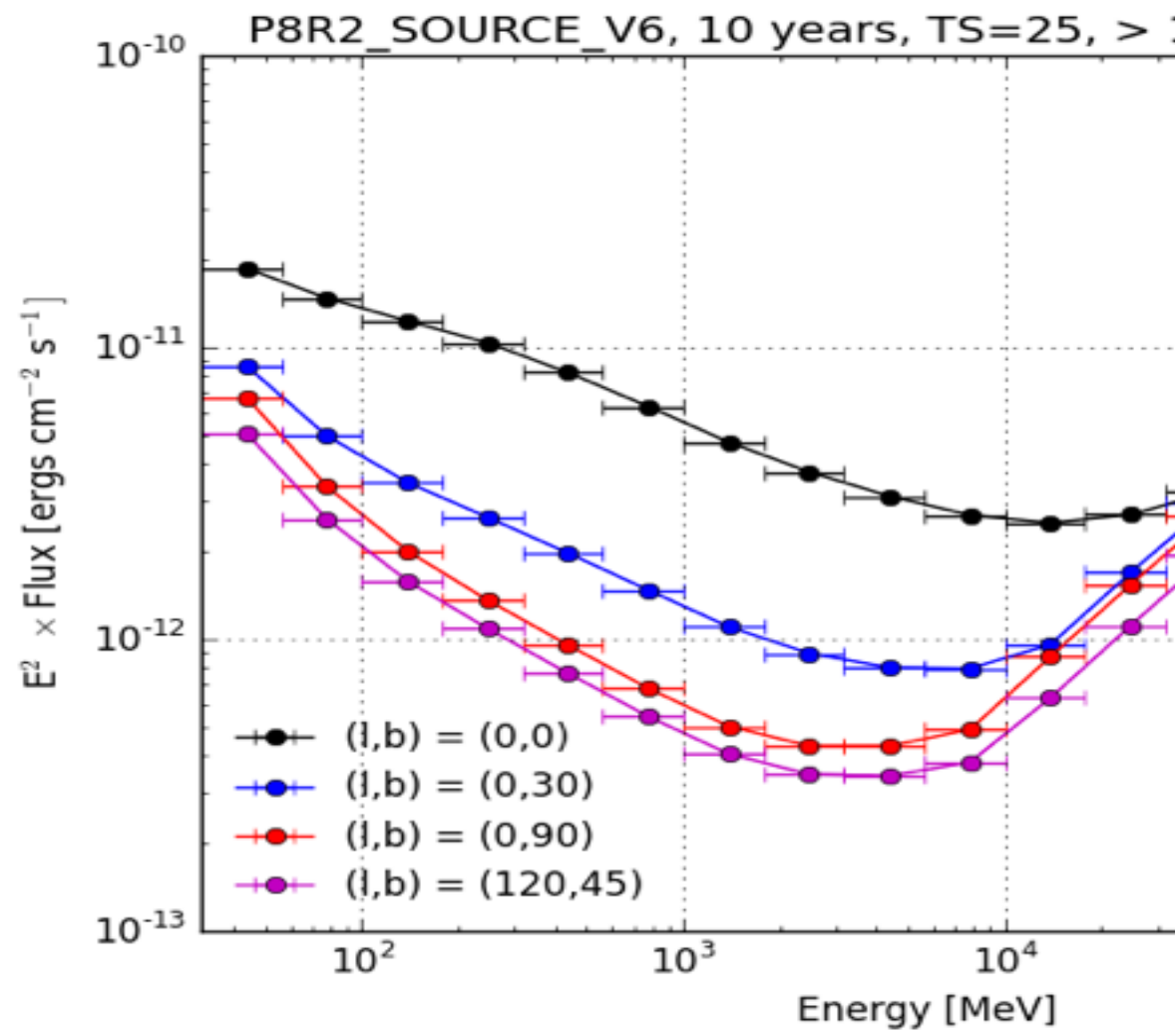
**Imaging Atmospheric
Cherenkov Telescope (IACT)**

Gamma-Ray Observatories



Gamma-Ray Observatories

FOV



GeV

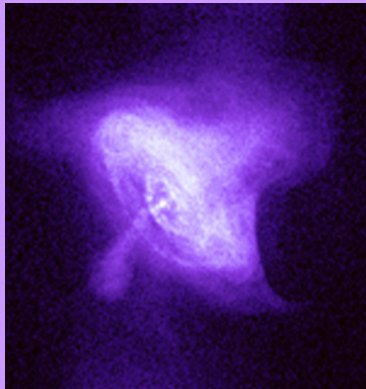
TeV

Energy

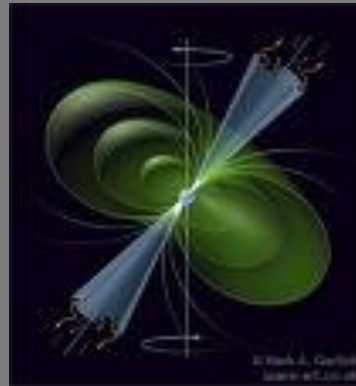
Gamma-Ray Astrophysics

Galactic

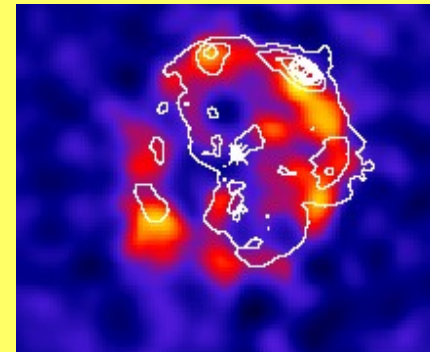
Pulsars Wind Nebula



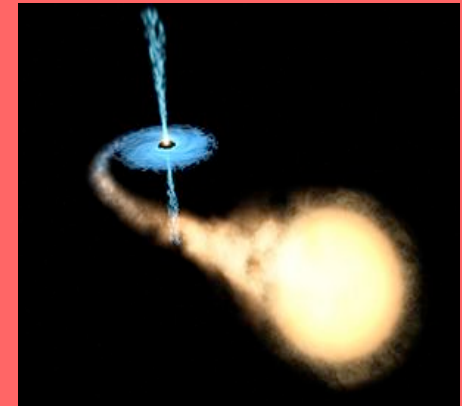
Pulsars



Supernova Remnant

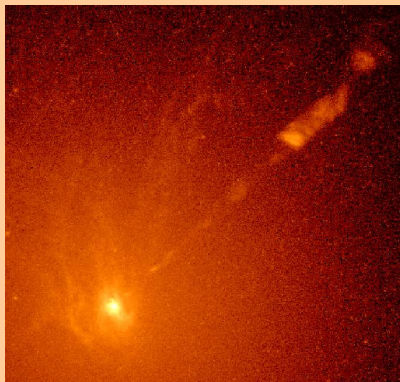


X-ray Binaries



Extragalactic

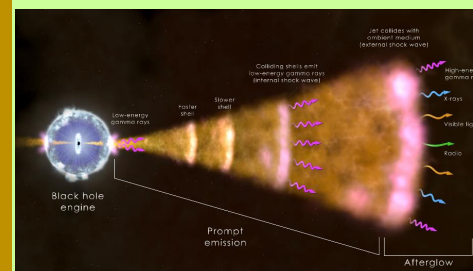
Active Galactic Nuclei



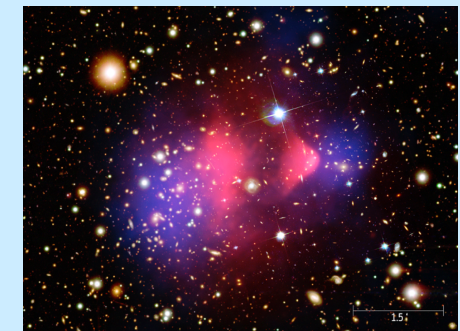
Starburst Galaxies



Gamma-Ray Burst

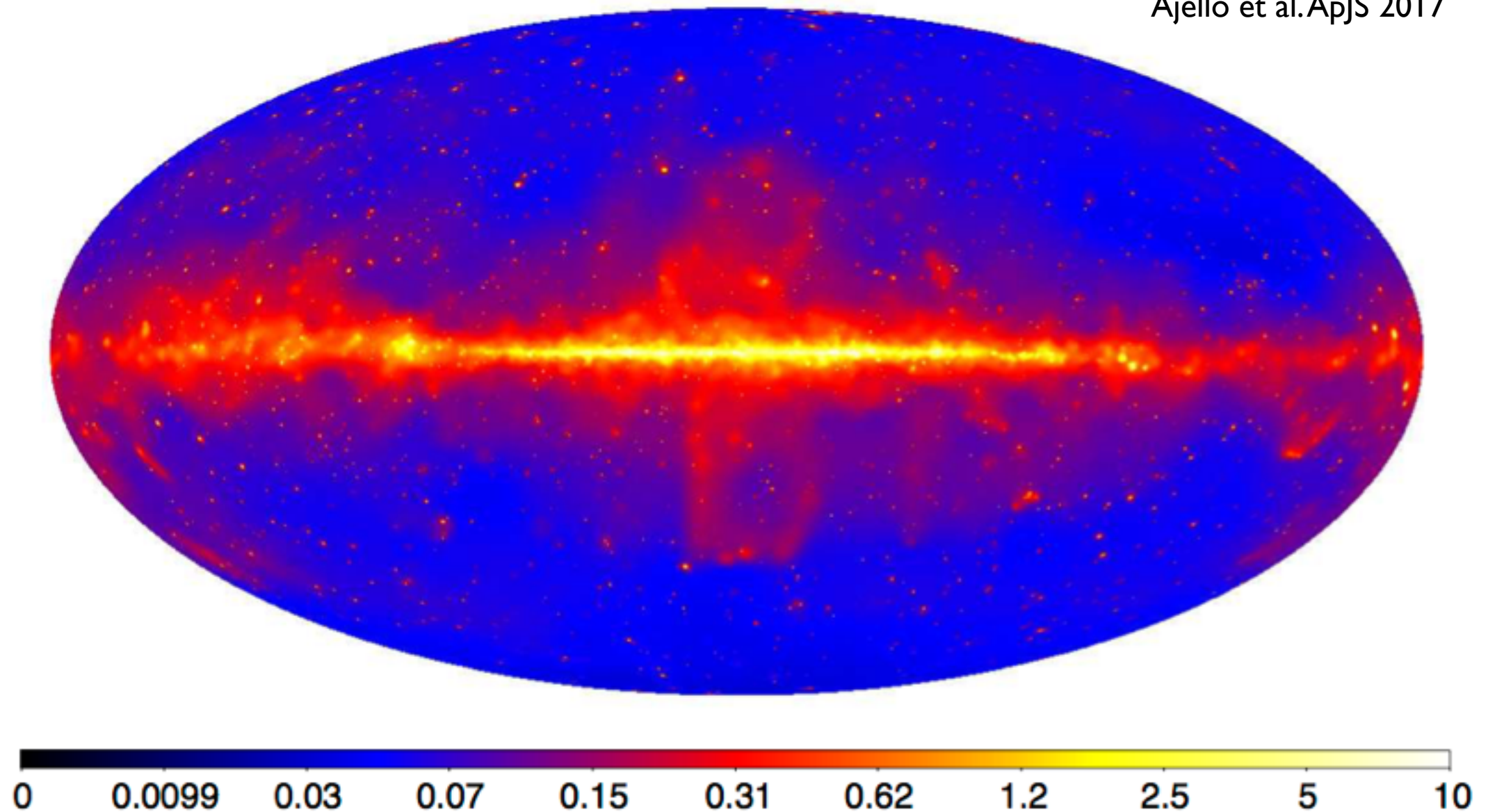


Indirect Dark Matter



GeV - TeV Sky Survey

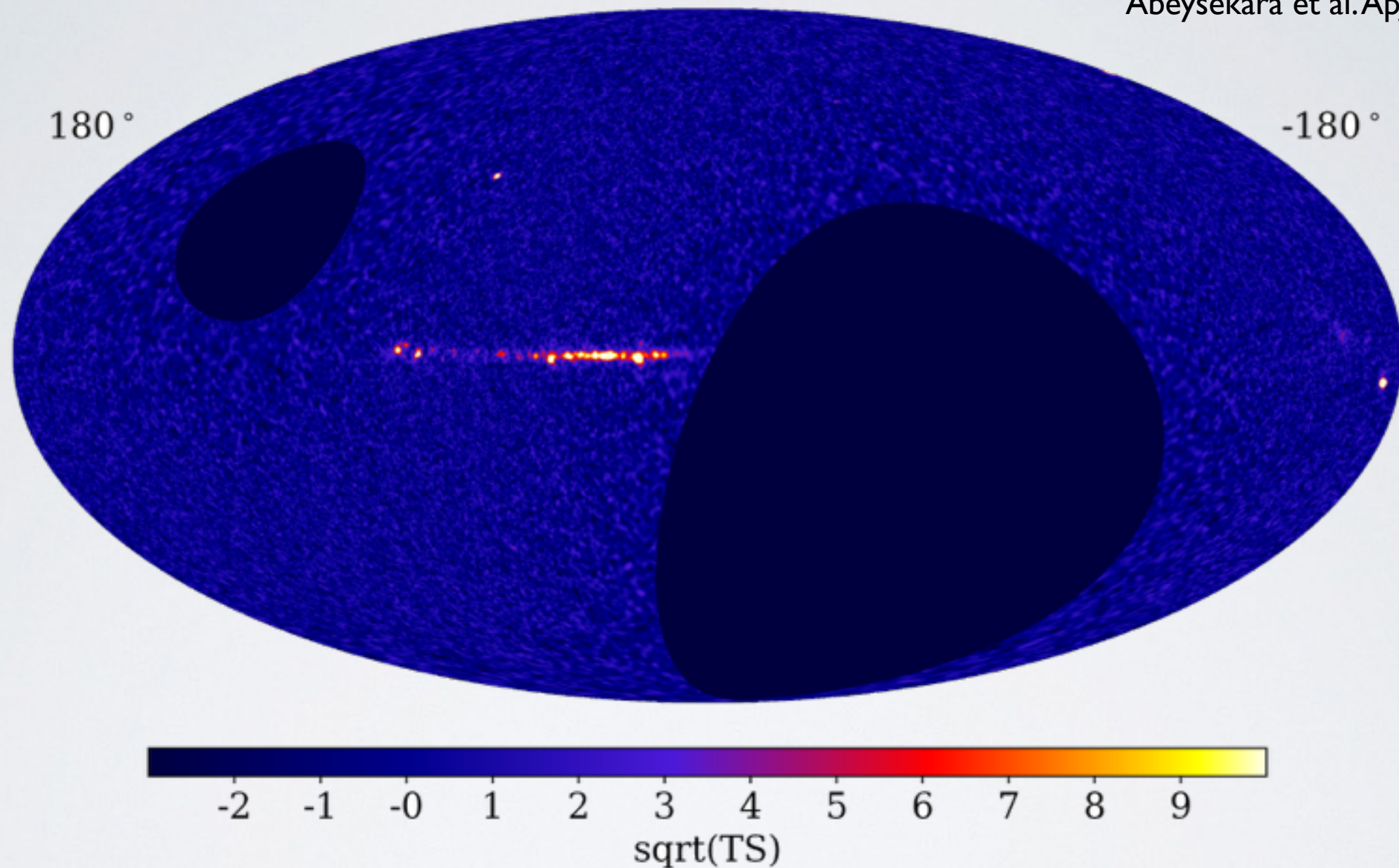
Ajello et al. ApJS 2017



Fermi-LAT count map 10 GeV — 2 TeV with >1500 objects in 84 months of data.

TeV Sky Survey

Abeysekara et al. ApJ 2017

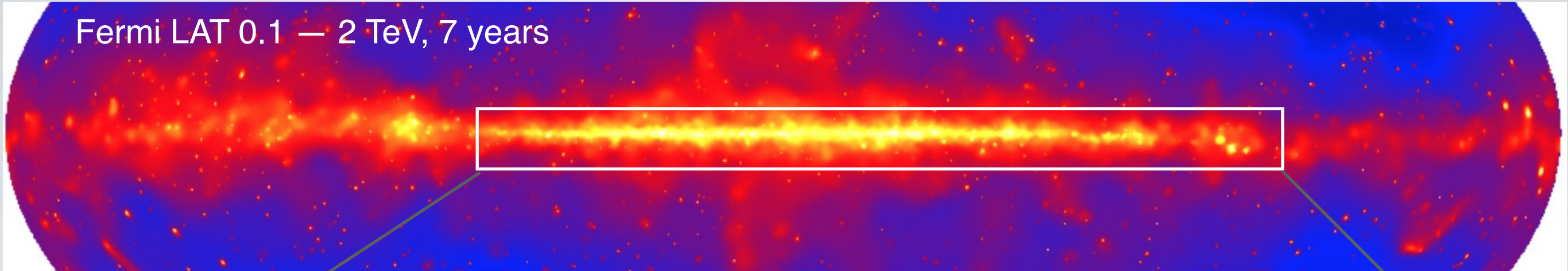


- HAWC TeV skymap in 17 months of data
- 39 2HWC sources: 2 blazars, 5 UID off the Galactic plane.

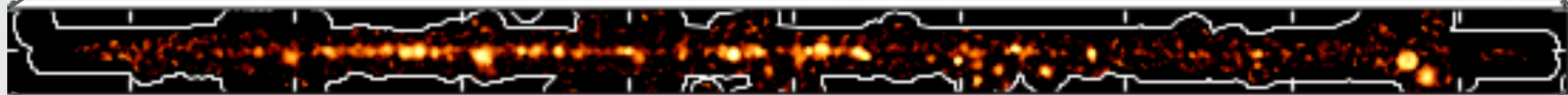
Gamma-ray view of our Galaxy



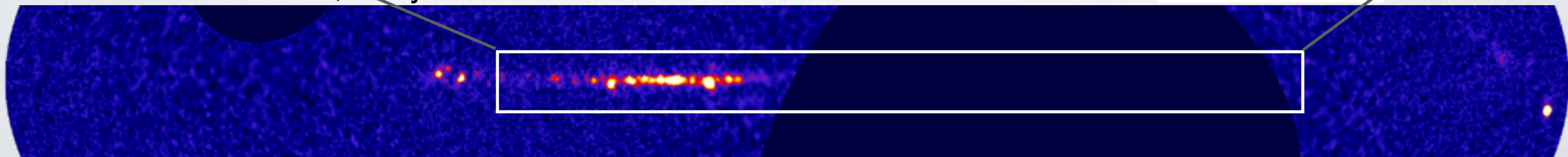
Fermi LAT 0.1 — 2 TeV, 7 years



HESS >1 TeV, 10 years



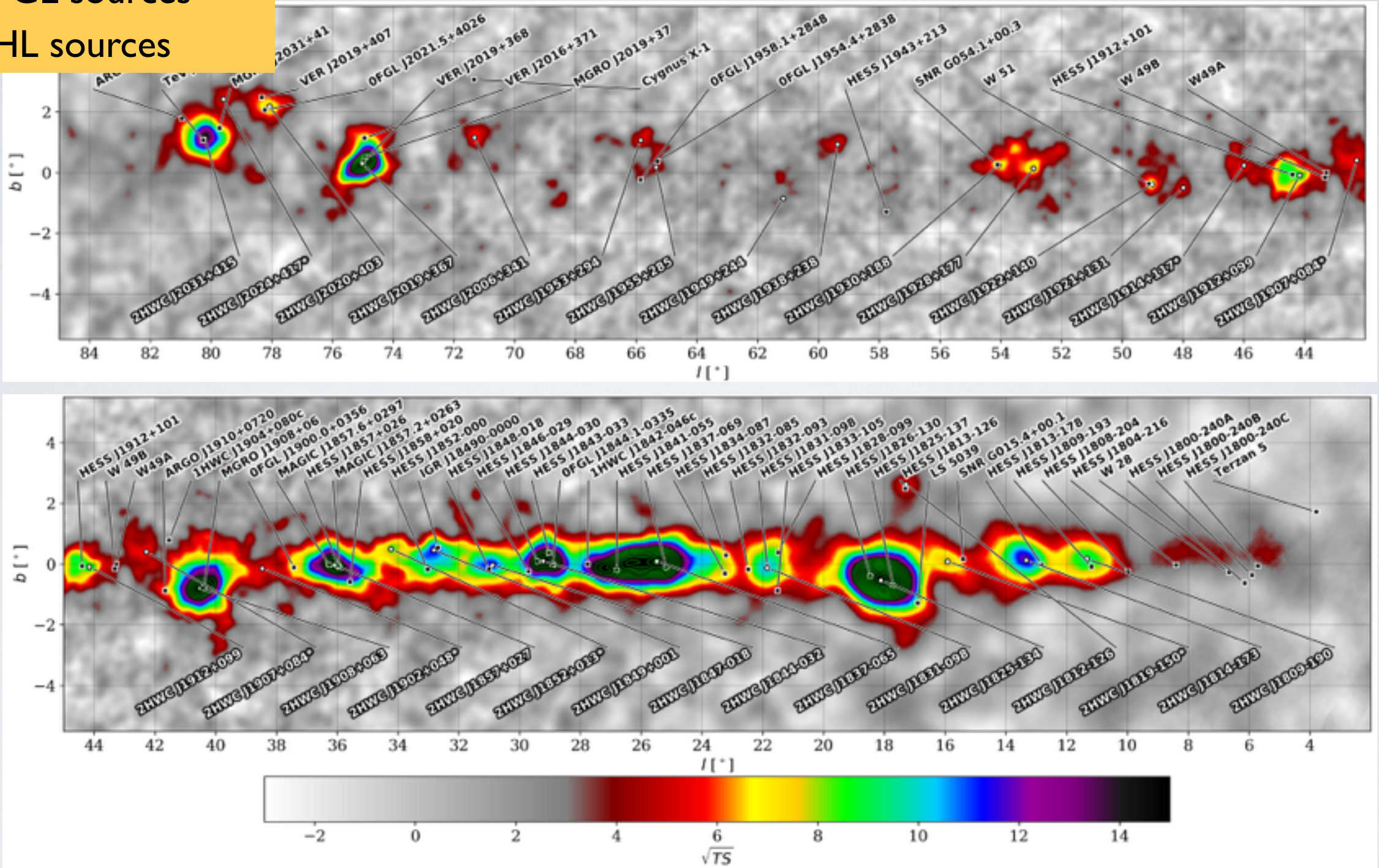
HAWC 0.1 — 100 TeV, 1.5 year



within this area (known extragalactic excluded):

- 150 3FGL sources
- 56 3FHL sources

Galactic Plane

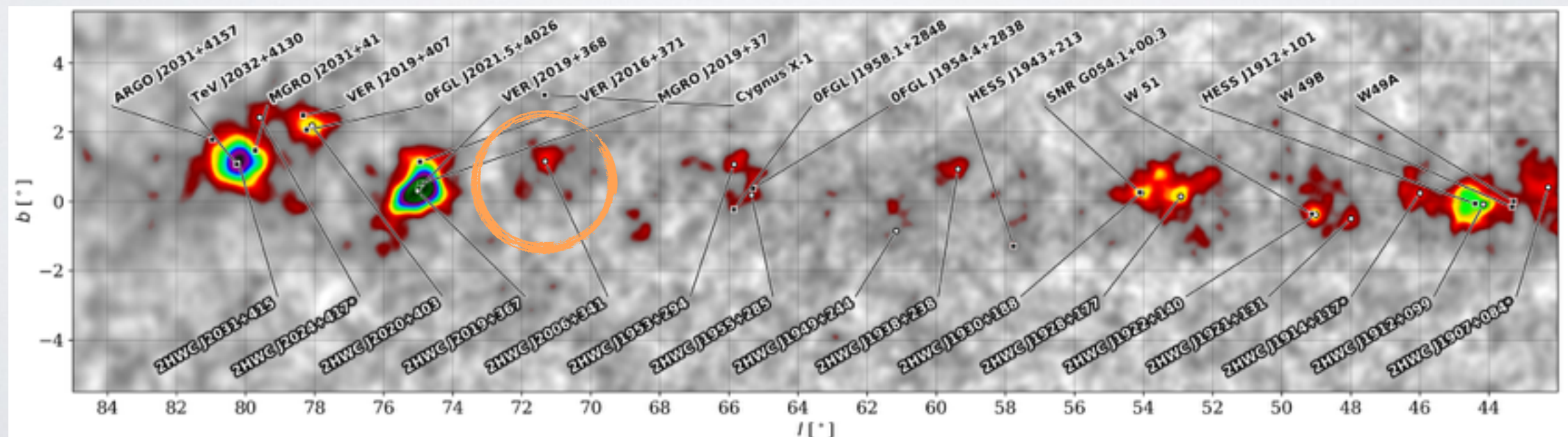
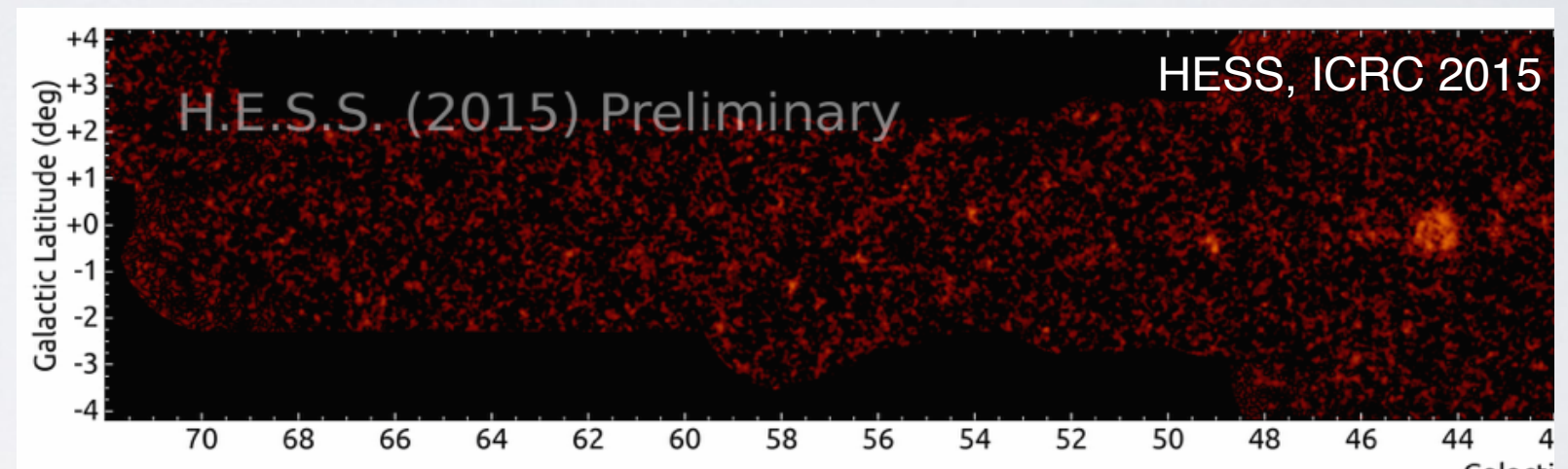
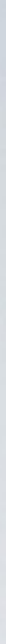


- 30 sources in the Galactic Plane (excluding Crab, Geminga, PSR B0656+14)
 - 16 likely associated with known TeV sources
 - 14 unassociated

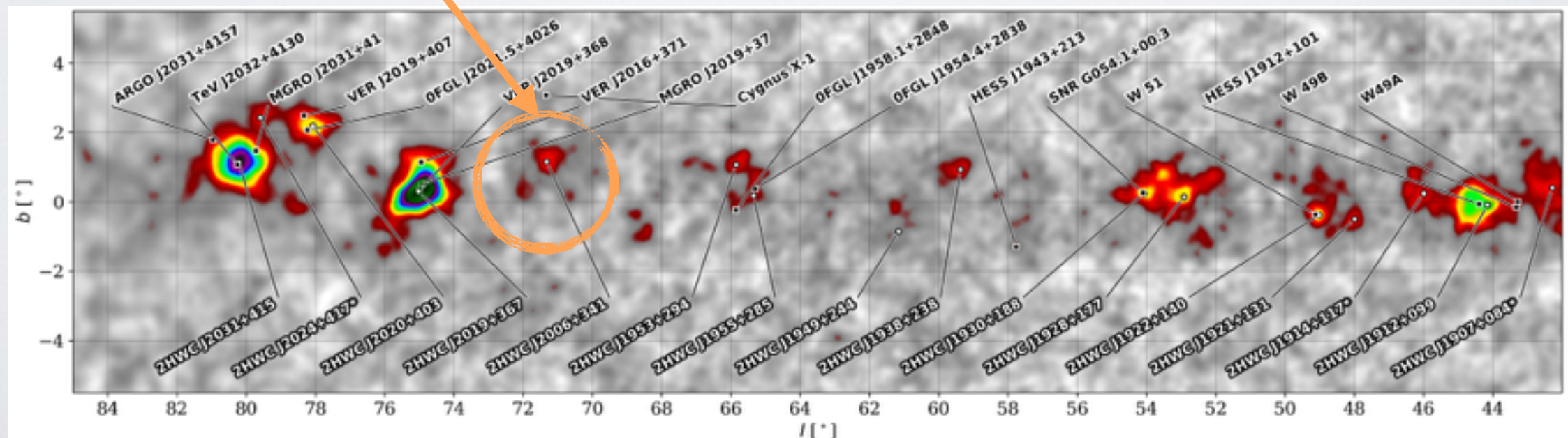
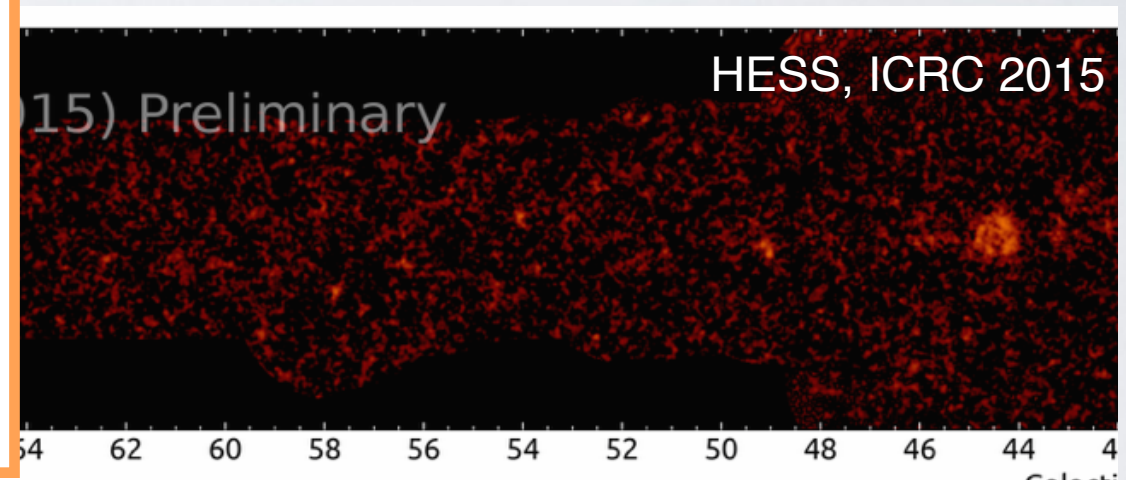
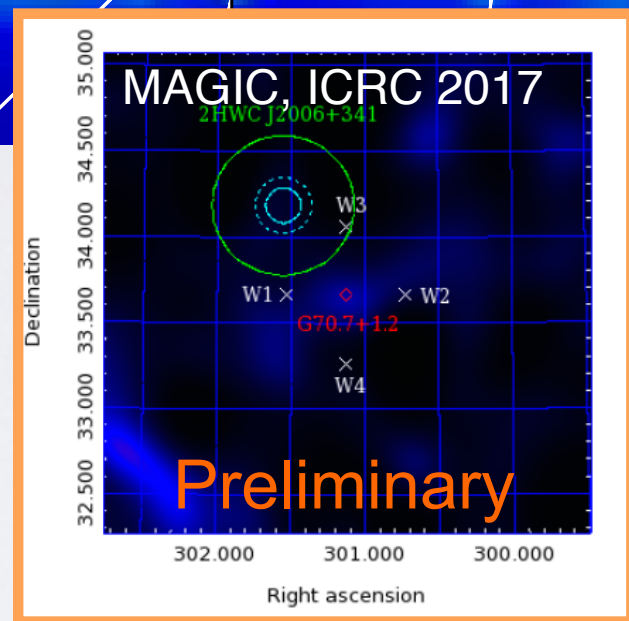
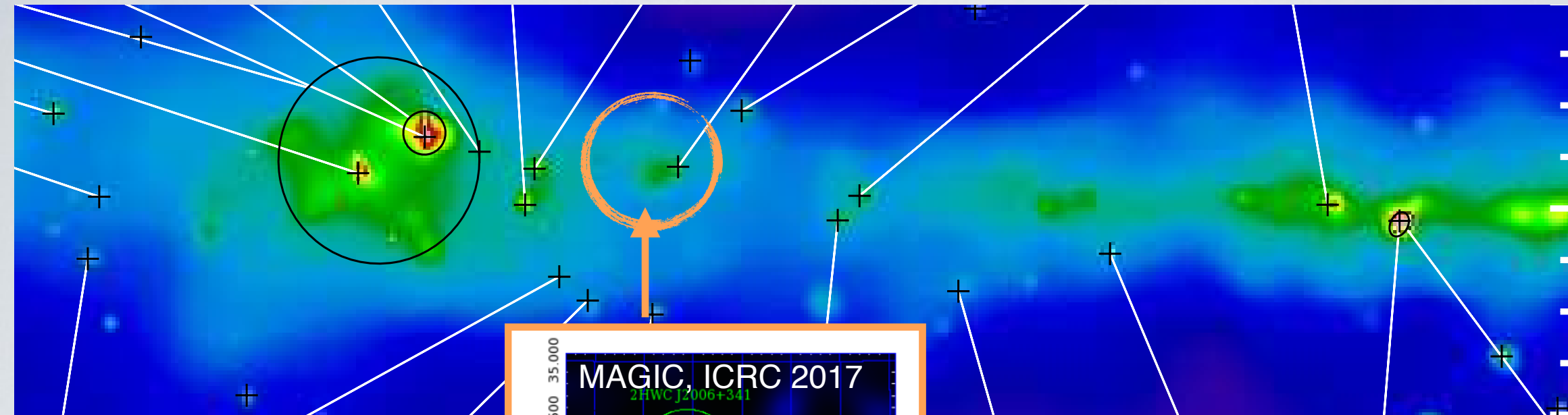
Talk by R. López-Coto. Mon, 16 Oct

Abeysekara et al. ApJ 2017

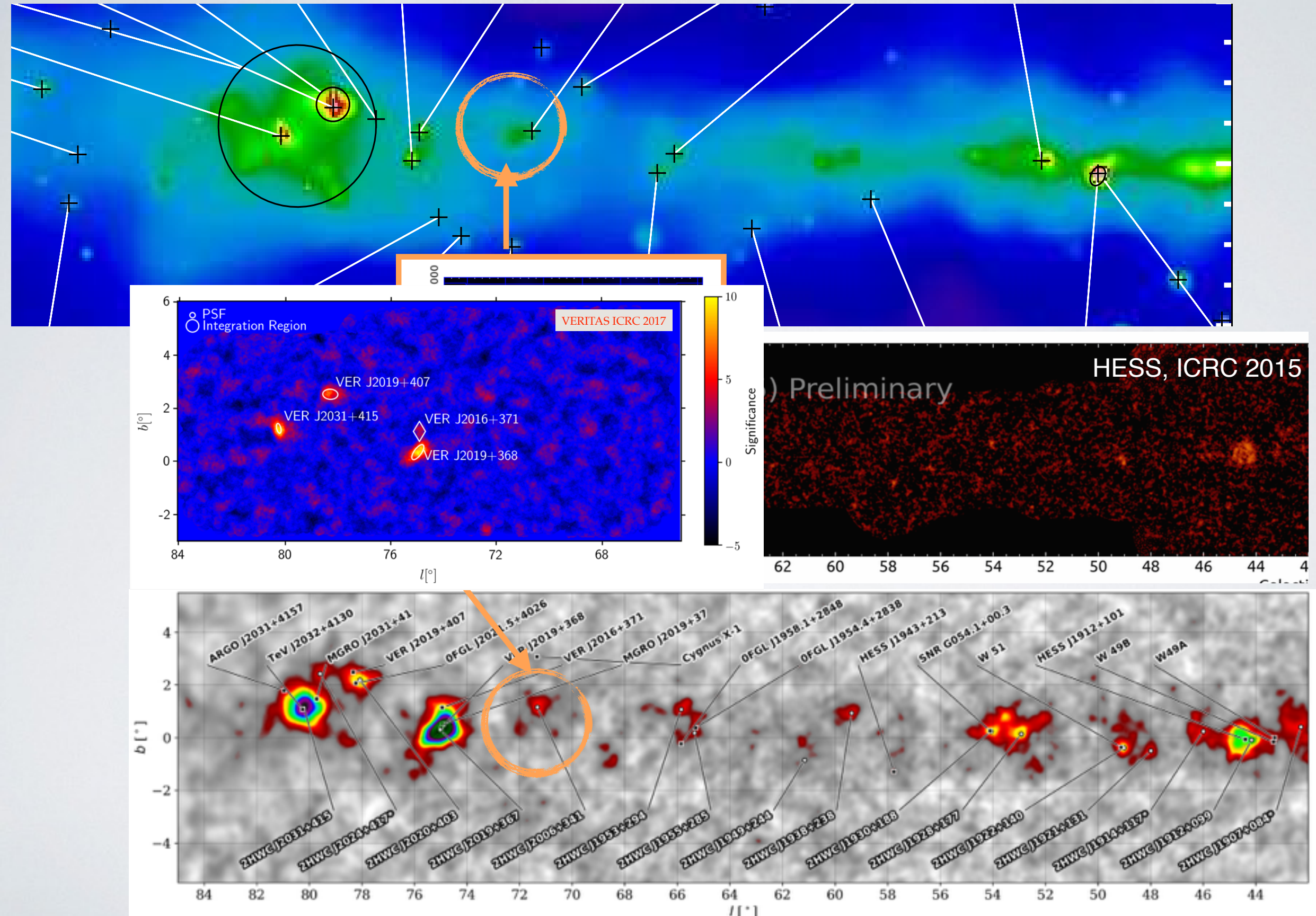
Galactic Plane



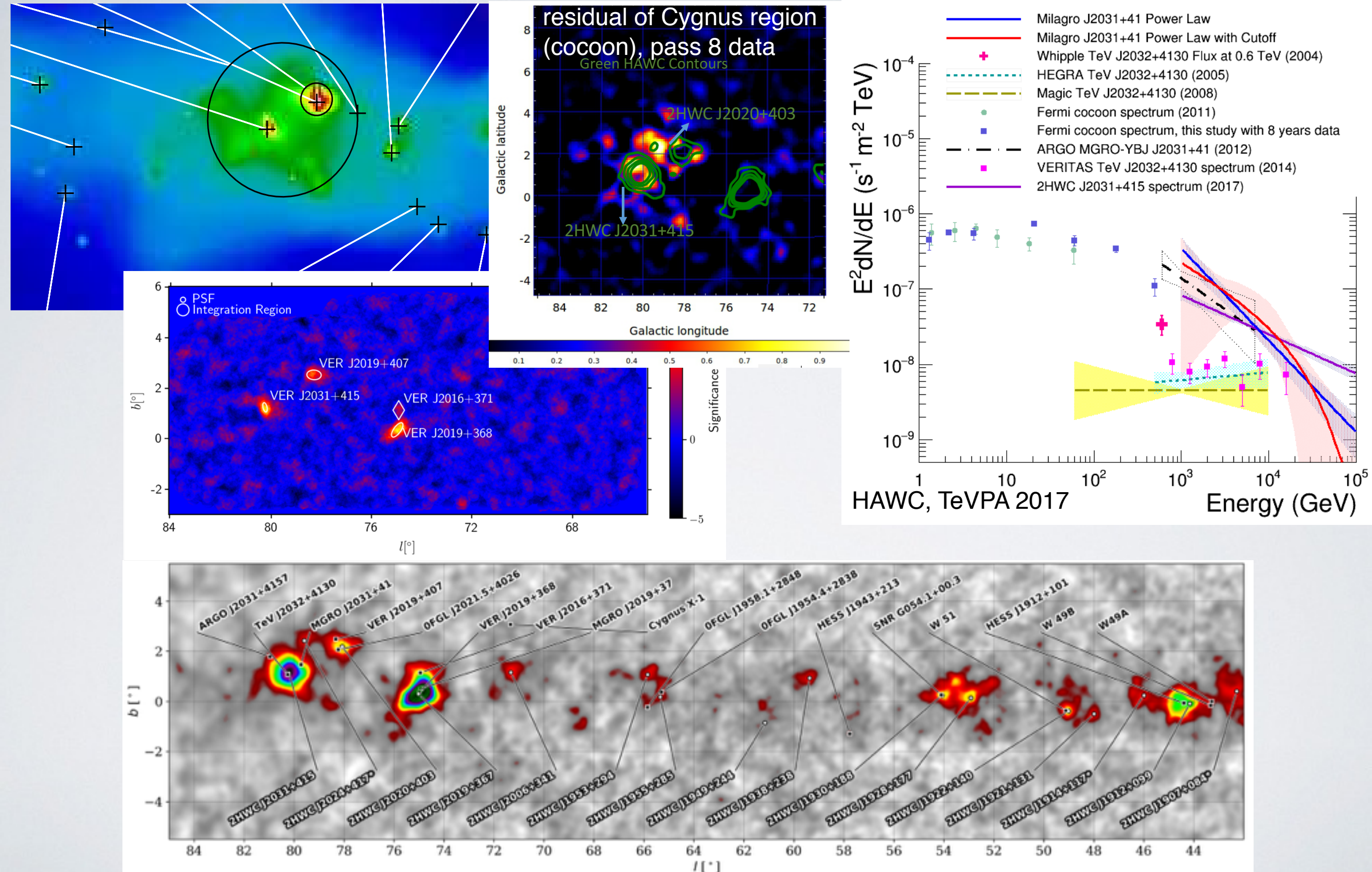
Galactic Plane

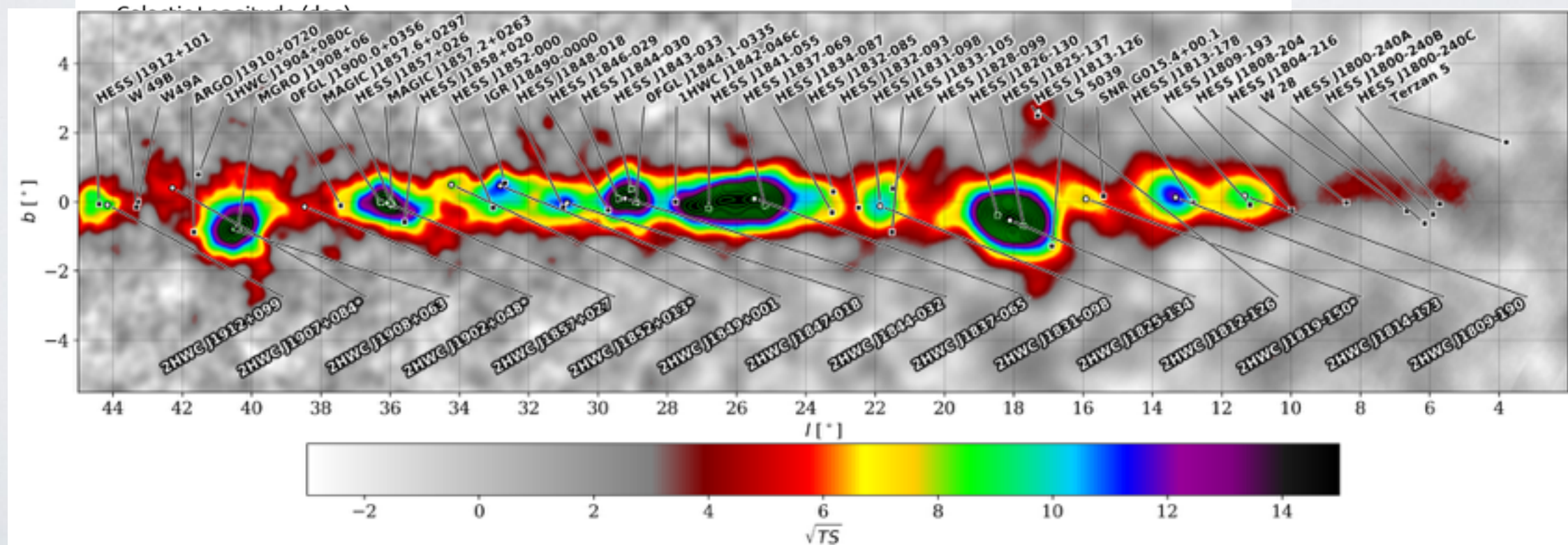
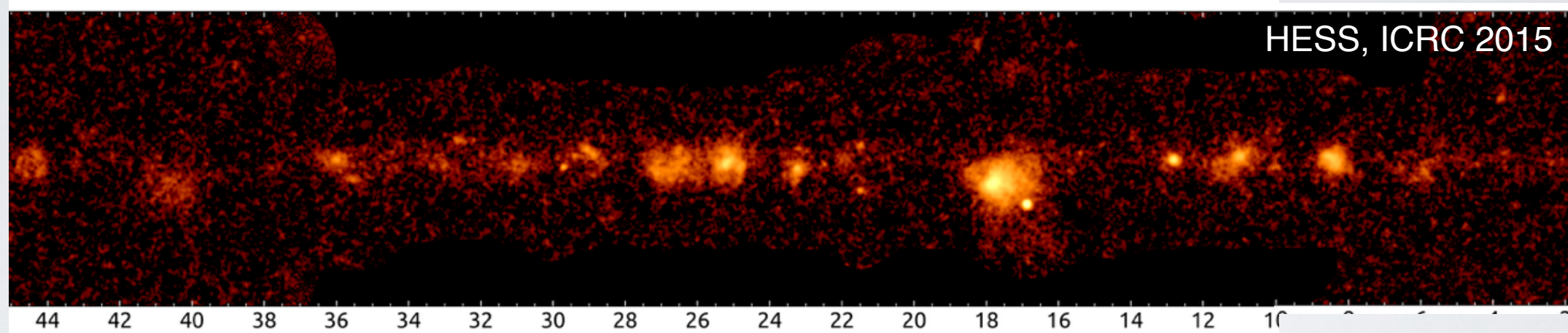
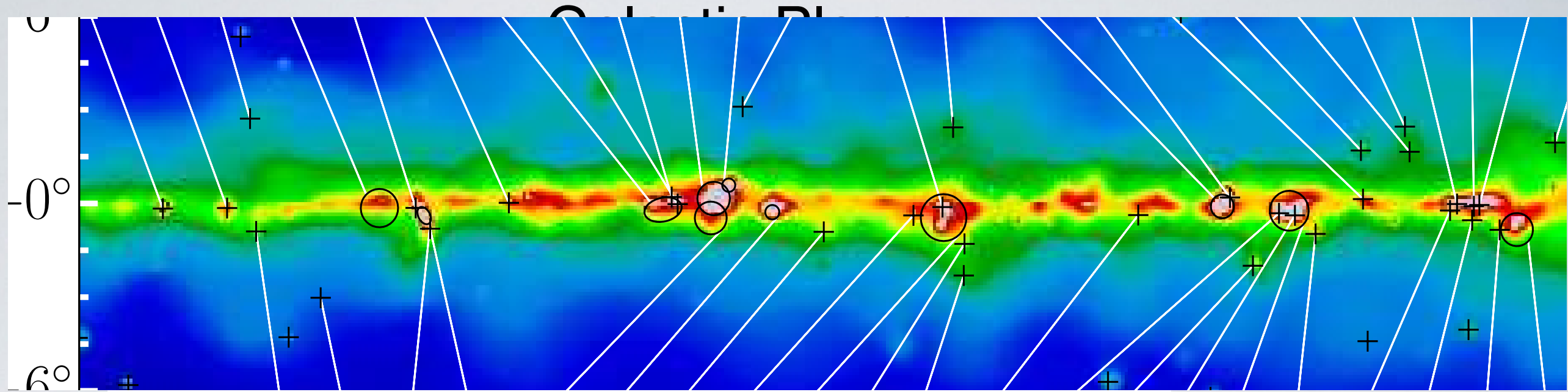


Galactic Plane



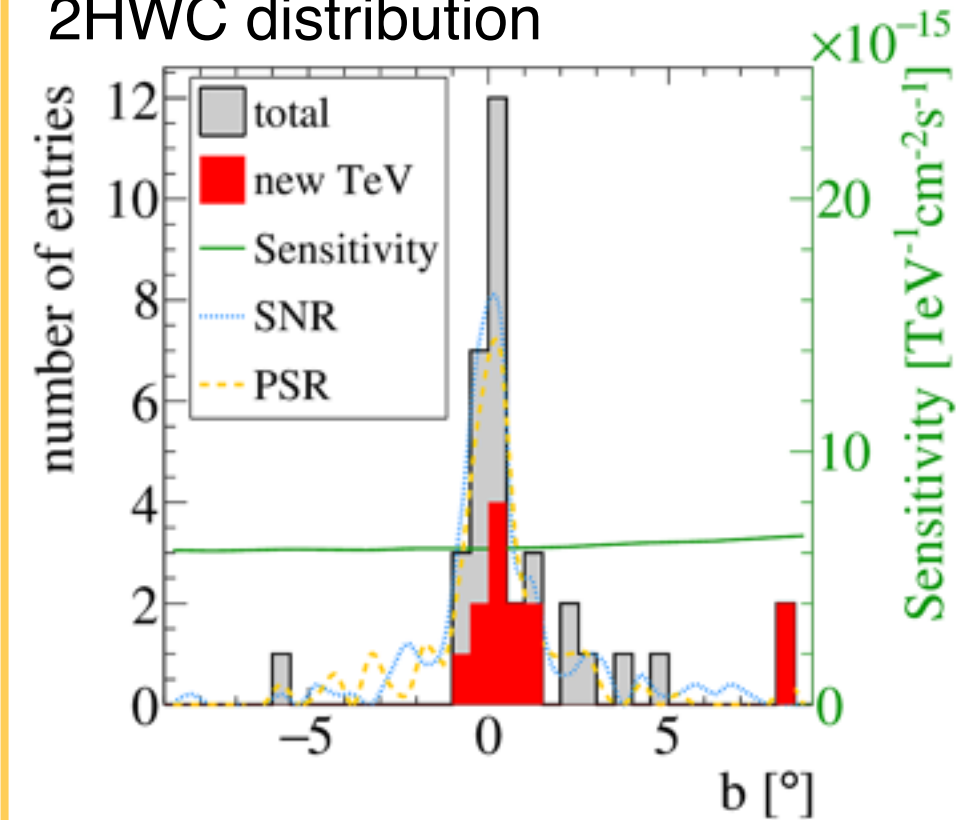
Galactic Plane



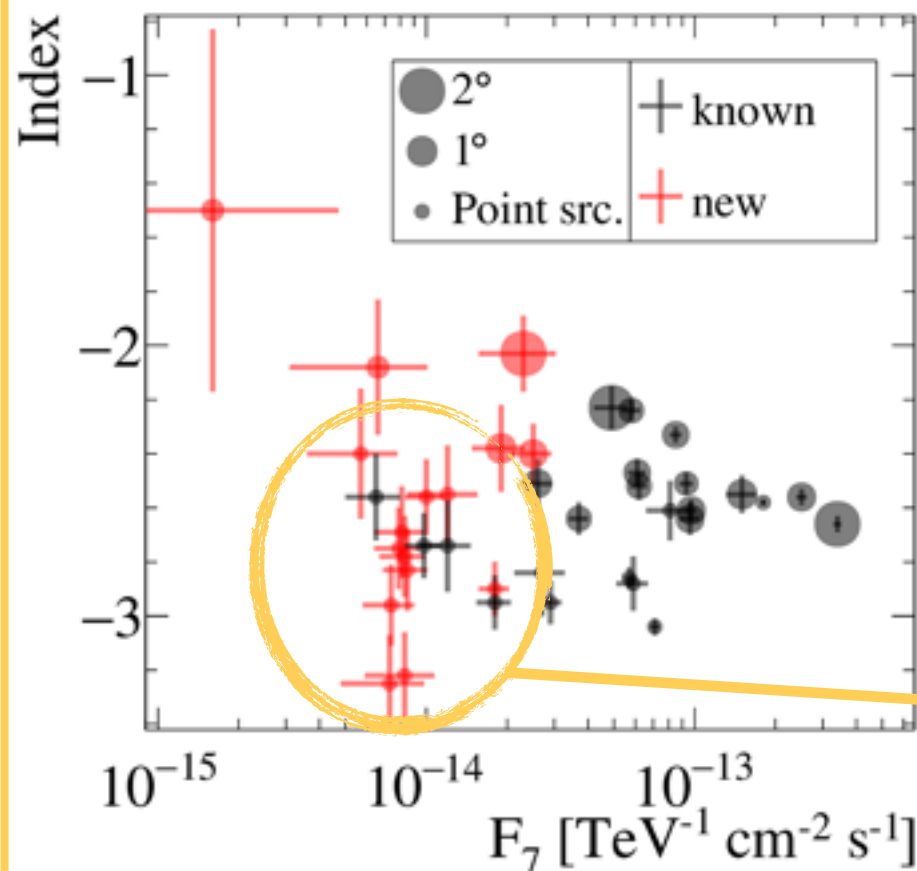
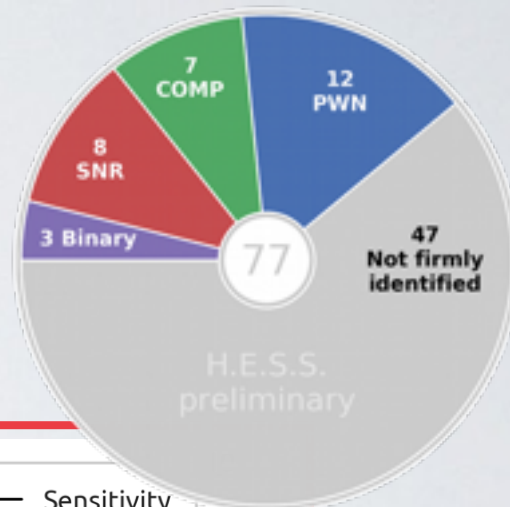
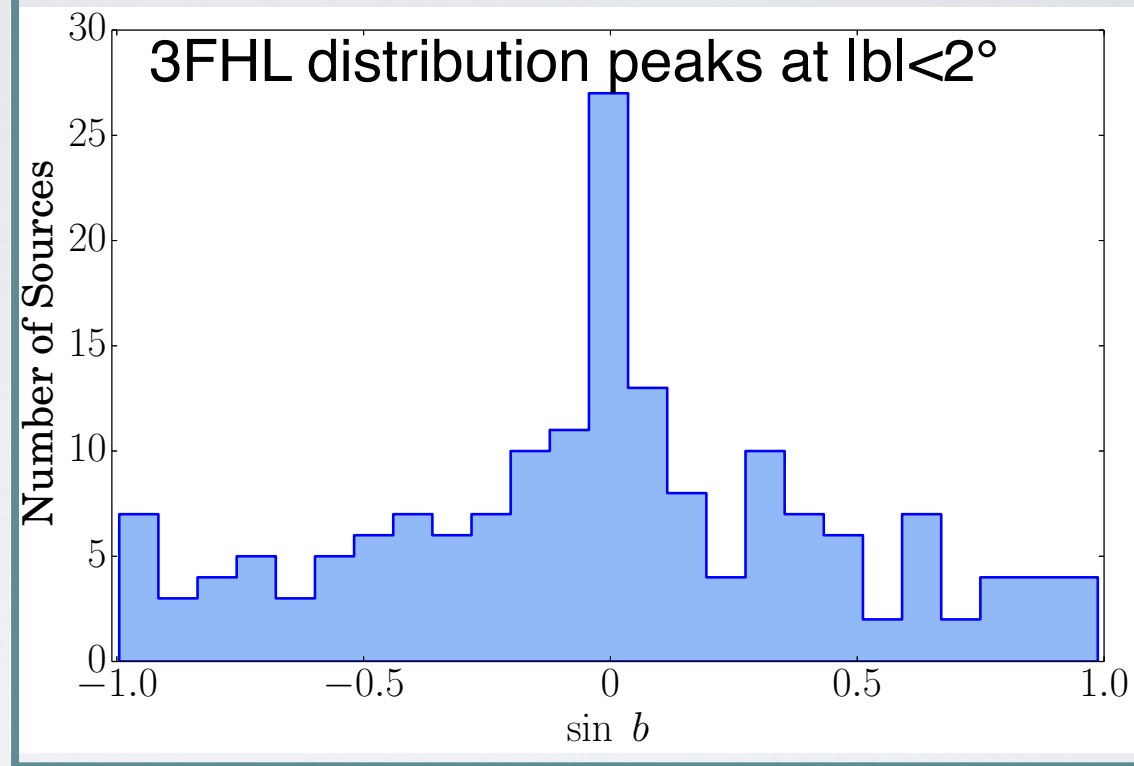


Galactic Plane Source Distribution

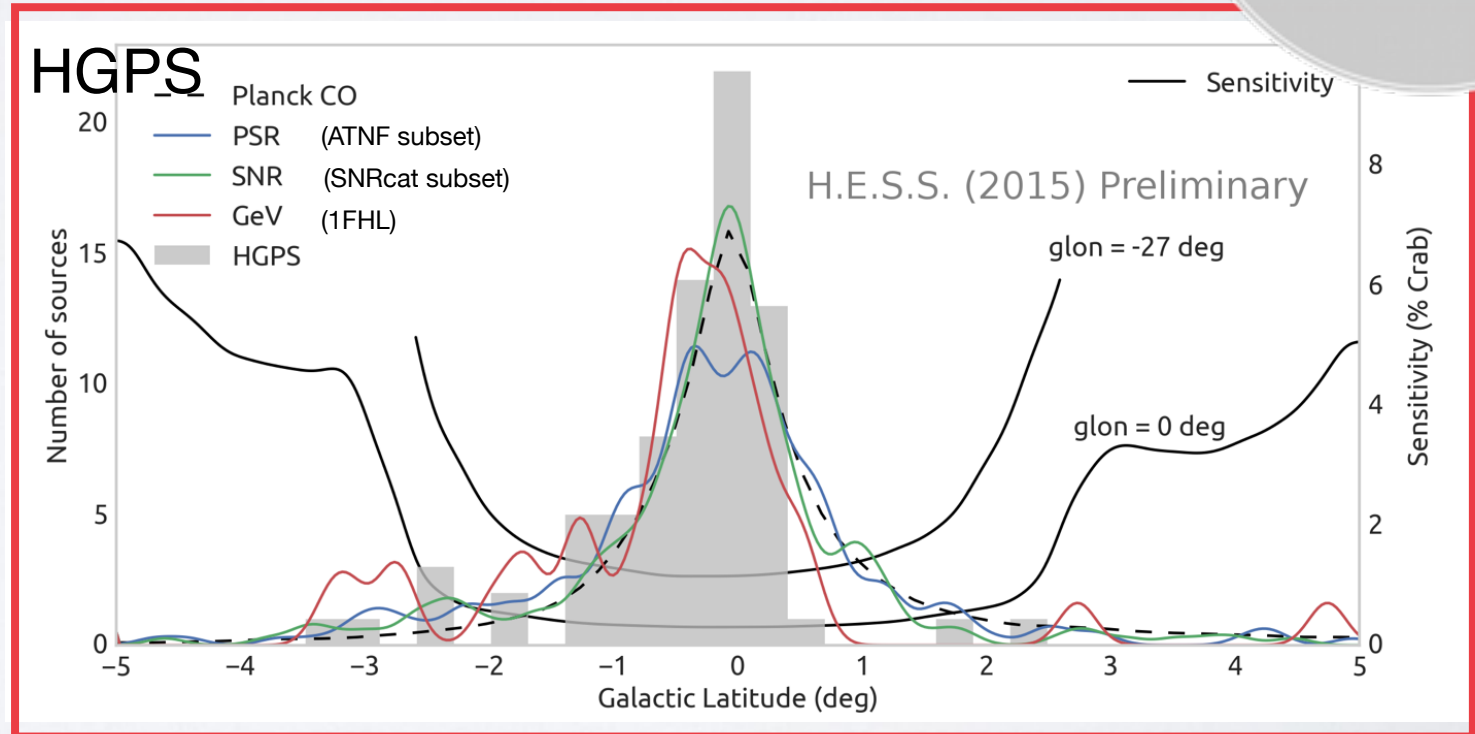
2HWC distribution



3FHL distribution peaks at $|b| < 2^\circ$



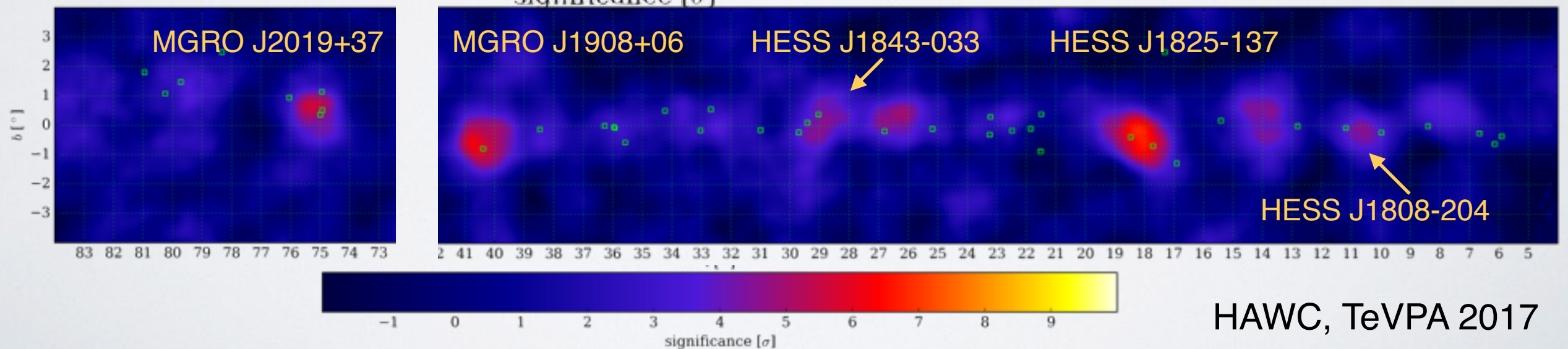
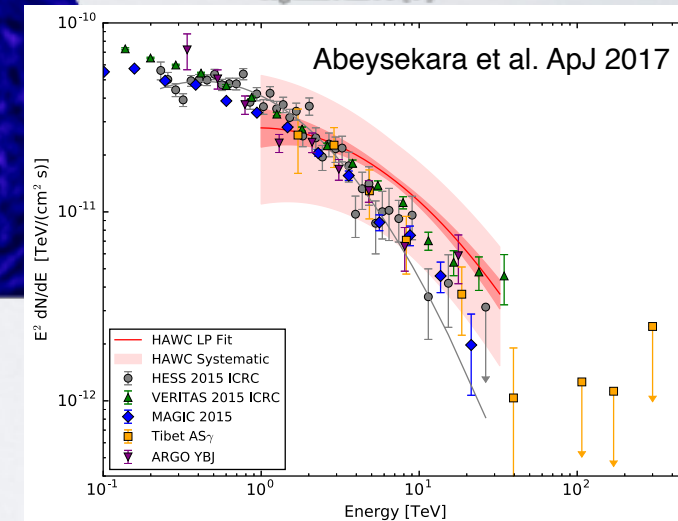
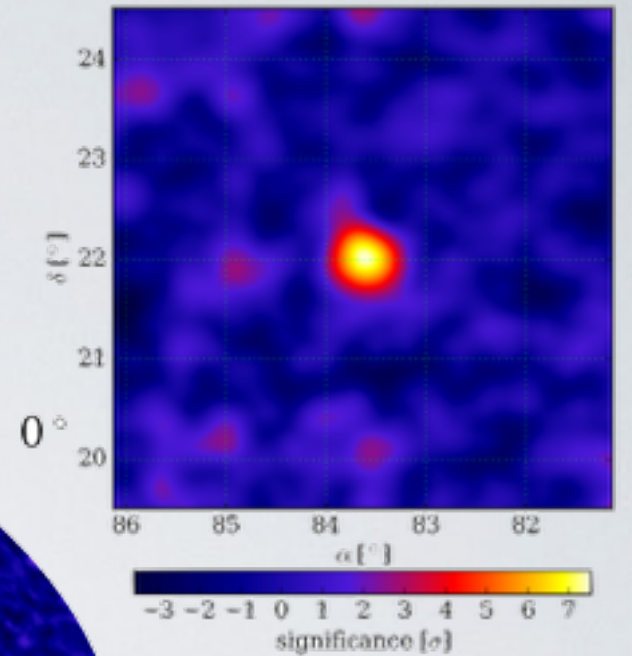
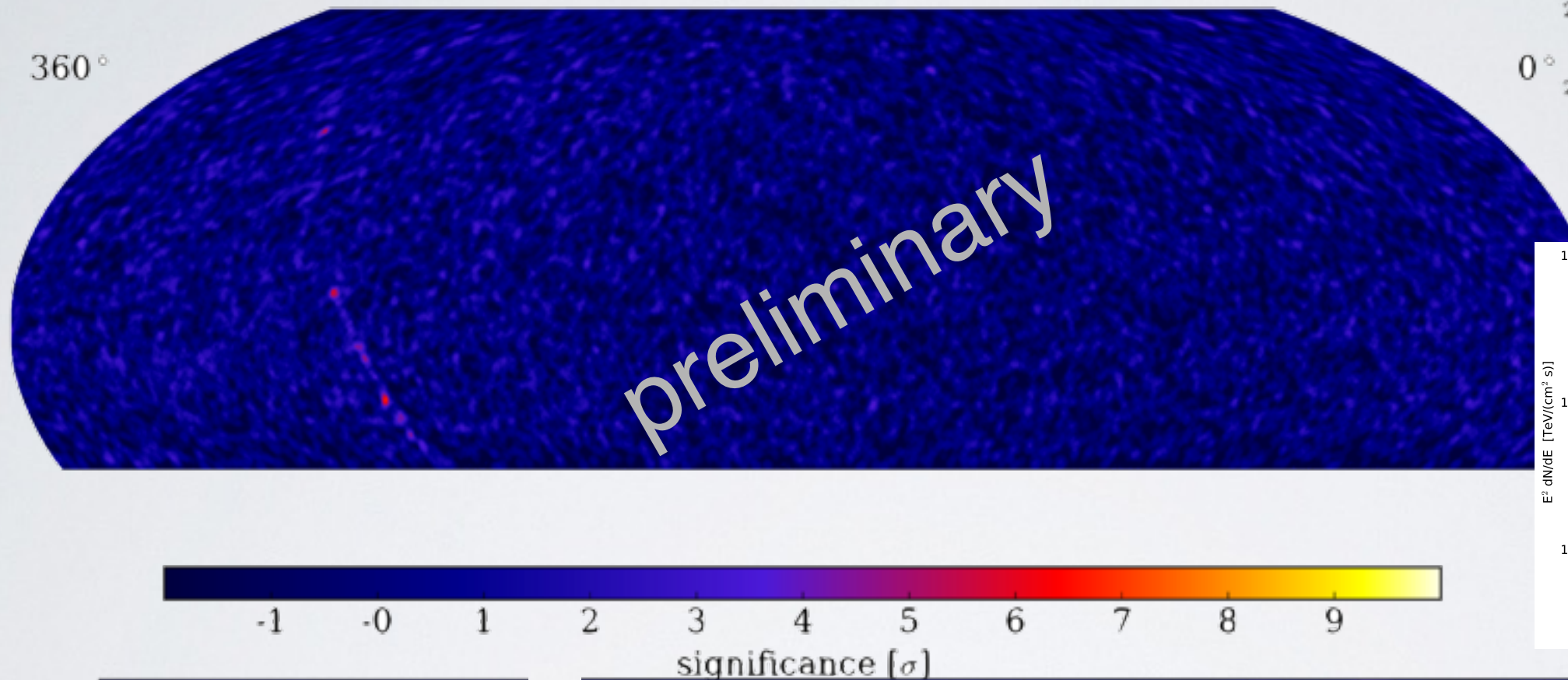
HGPS



Good candidates for follow-up by pointing instruments.

Galactic Plane at >50 TeV

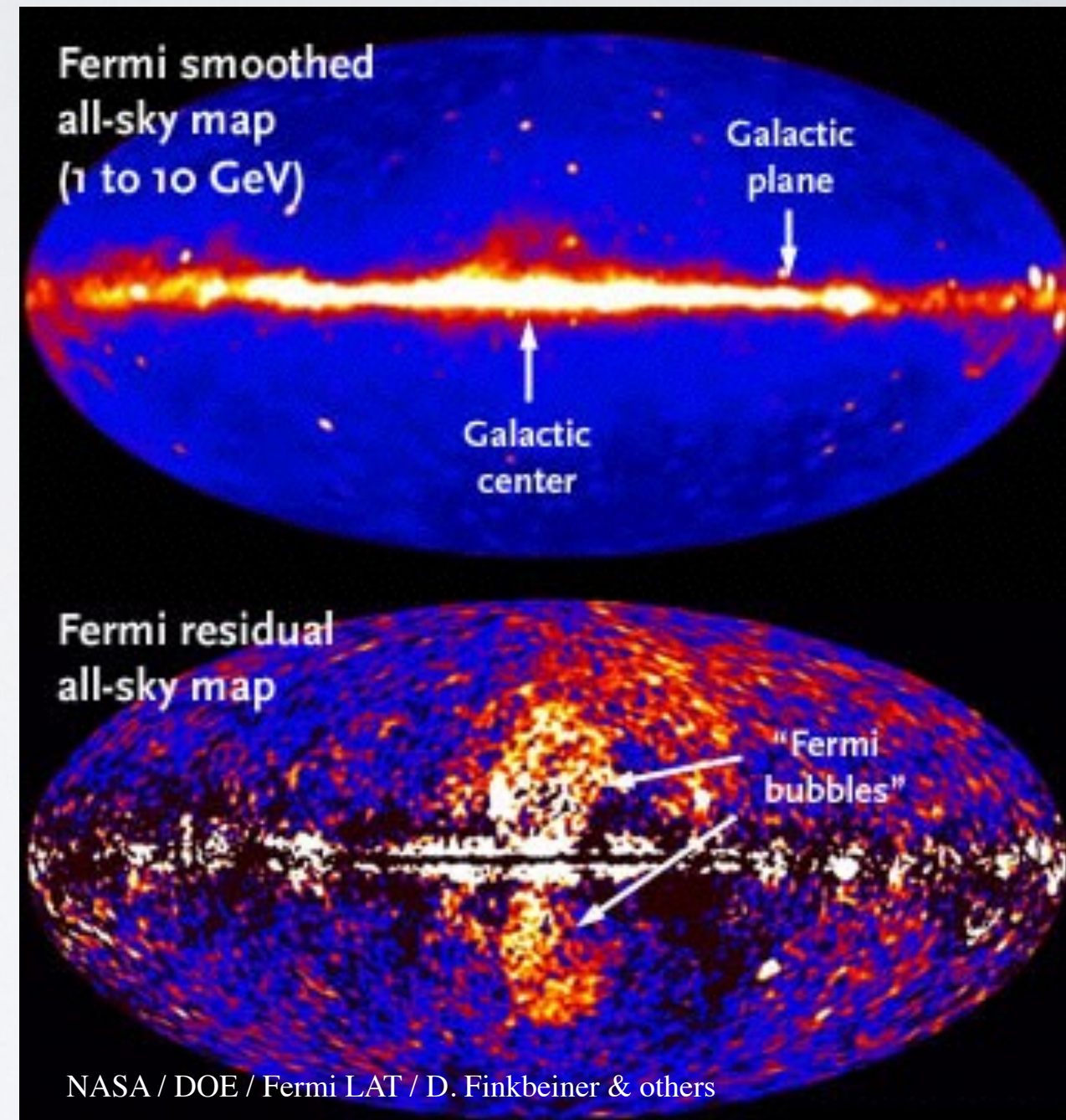
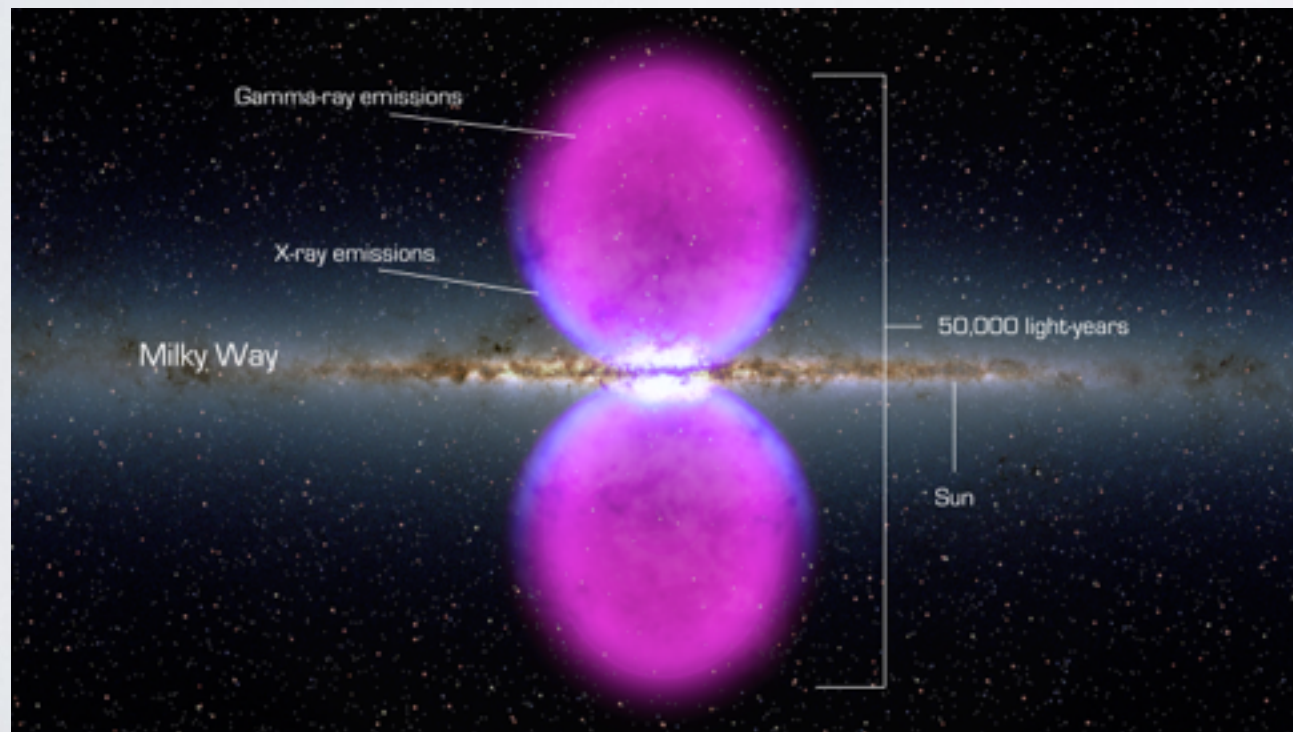
1deg extended map at >50 TeV



HAWC, TeVPA 2017

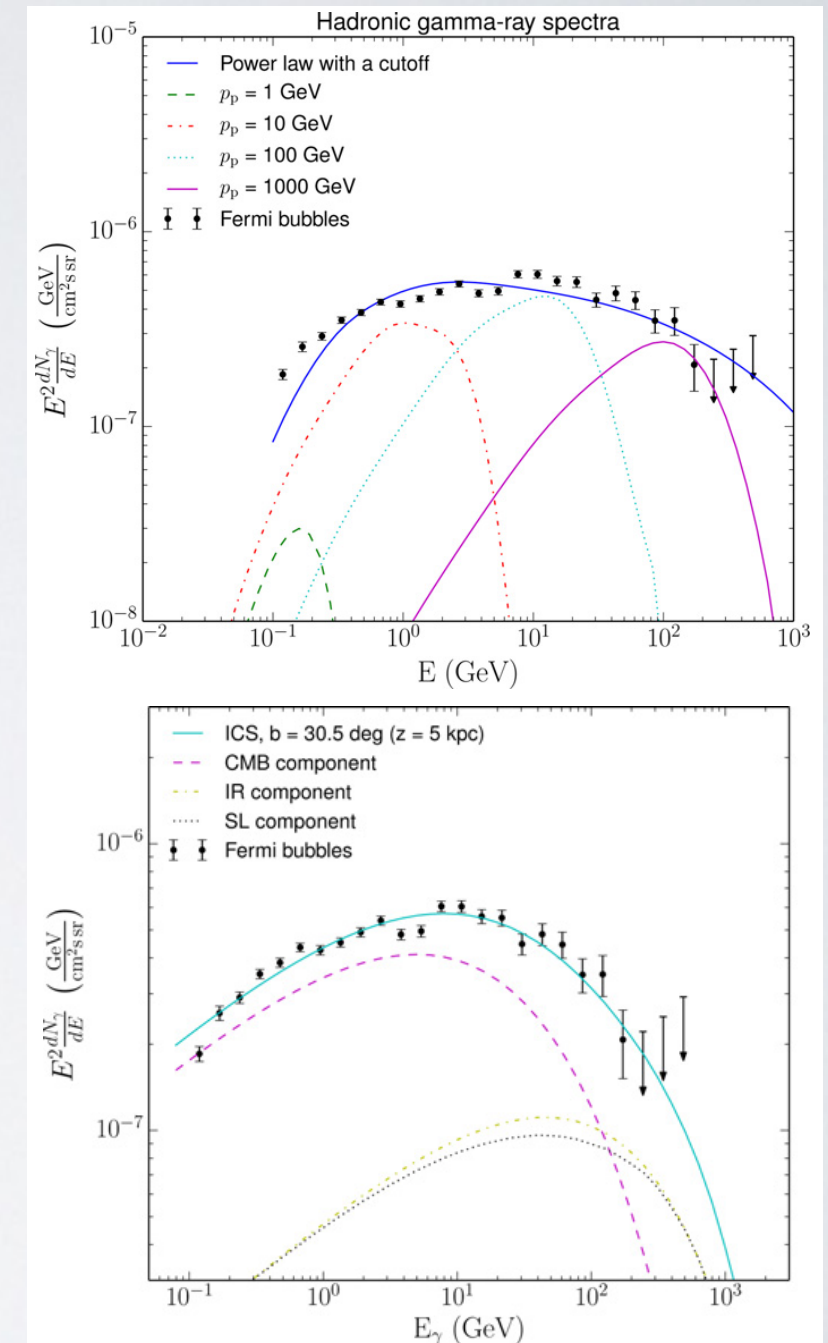
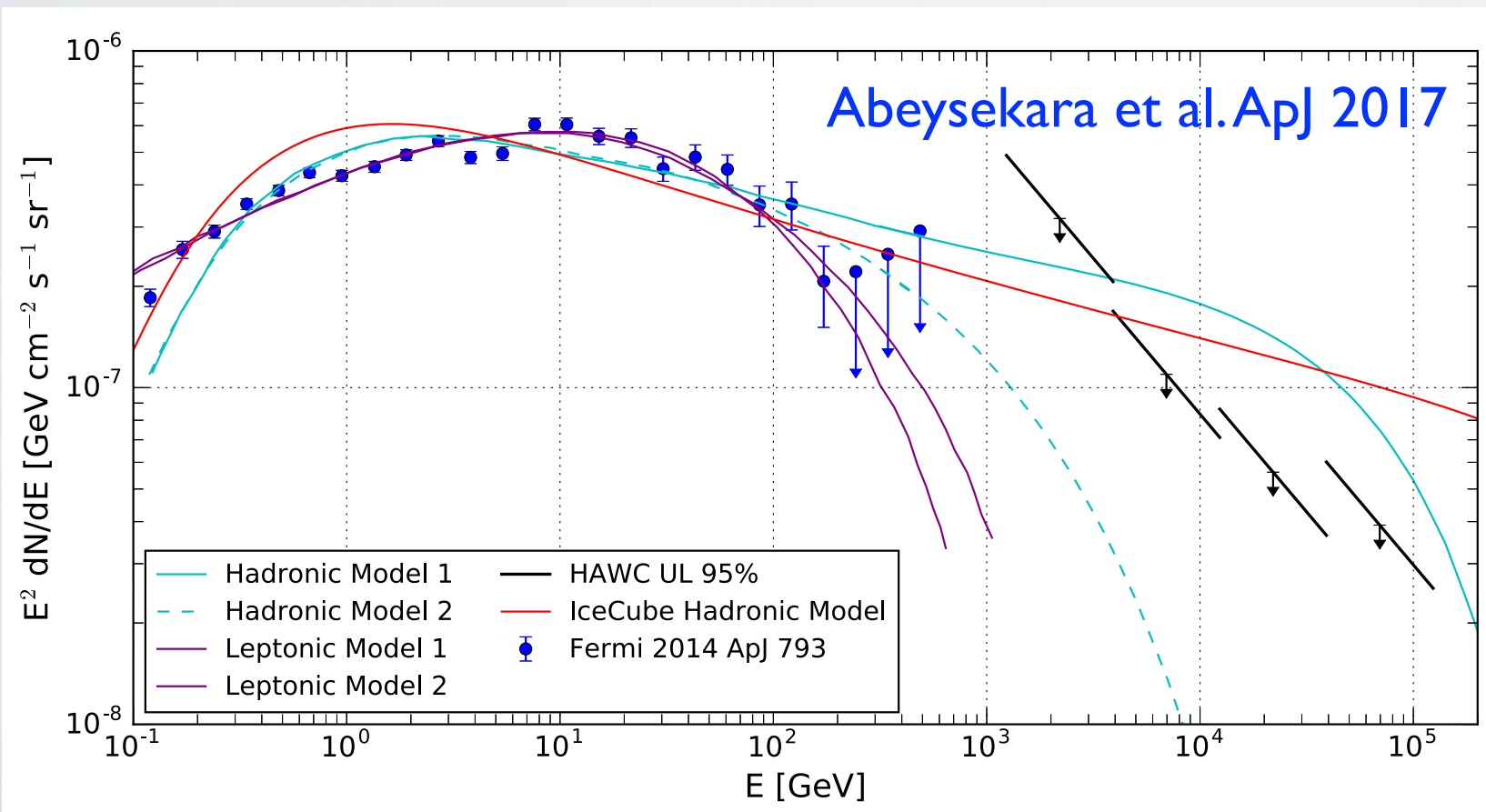
Large-scale structures e.g. Fermi Bubbles

- Large scale, non-uniform structures extending above and below the Galactic center.
- Edges line up with X-ray features.
- Correlate with microwave excess (WMAP haze)
- Both hadronic and leptonic model fit Fermi LAT data. Leptonic model can explain both gamma ray and microwave excess.



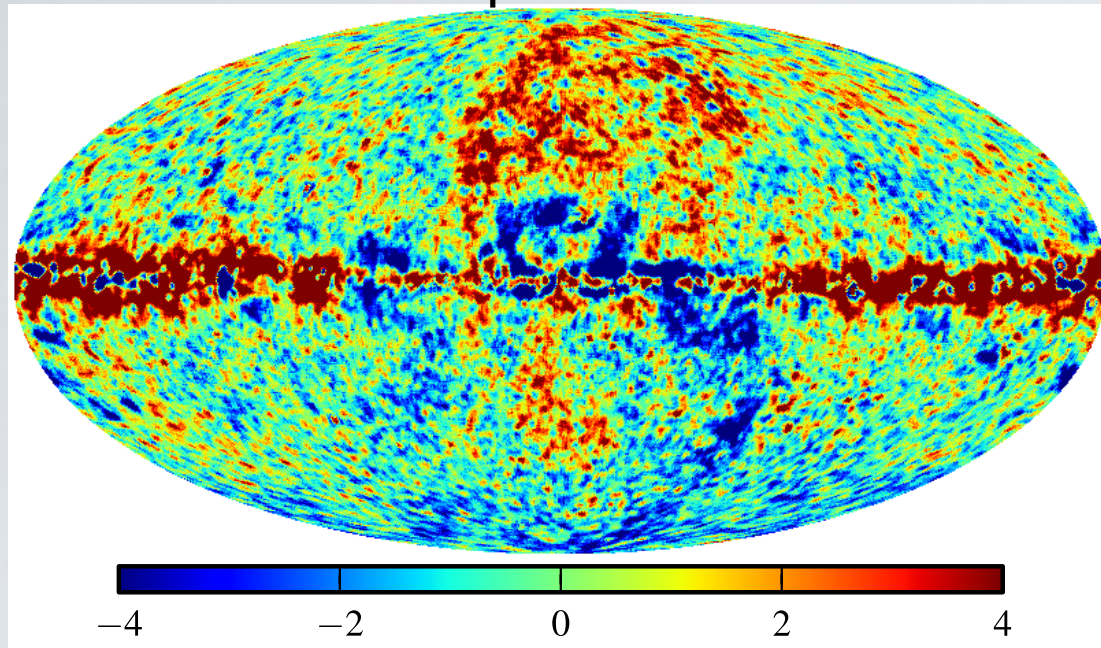
Large-scale structures e.g. Fermi Bubbles

- Hadronic model:
 - cosmic ray interacting with interstellar matter
 - hard to explain microwave haze
- Leptonic model:
 - electron population produced by outflow from Galactic center, or reaccelerated inside the bubble
- First limits in TeV, **hard spectrum is highly unlikely.**



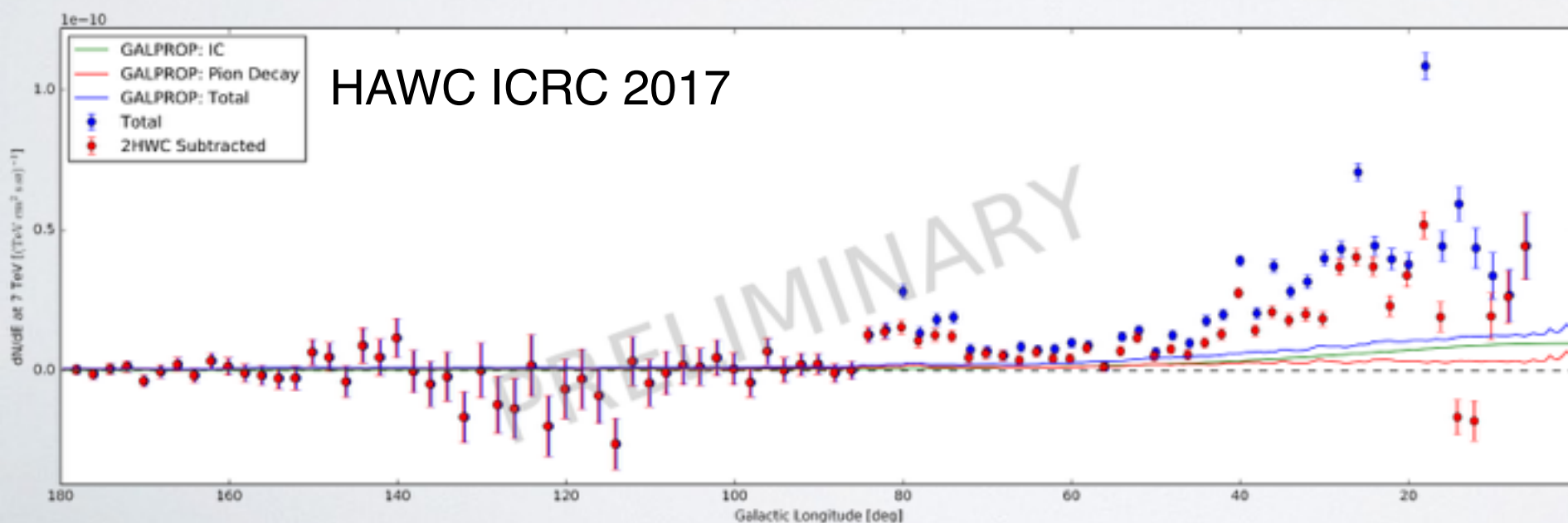
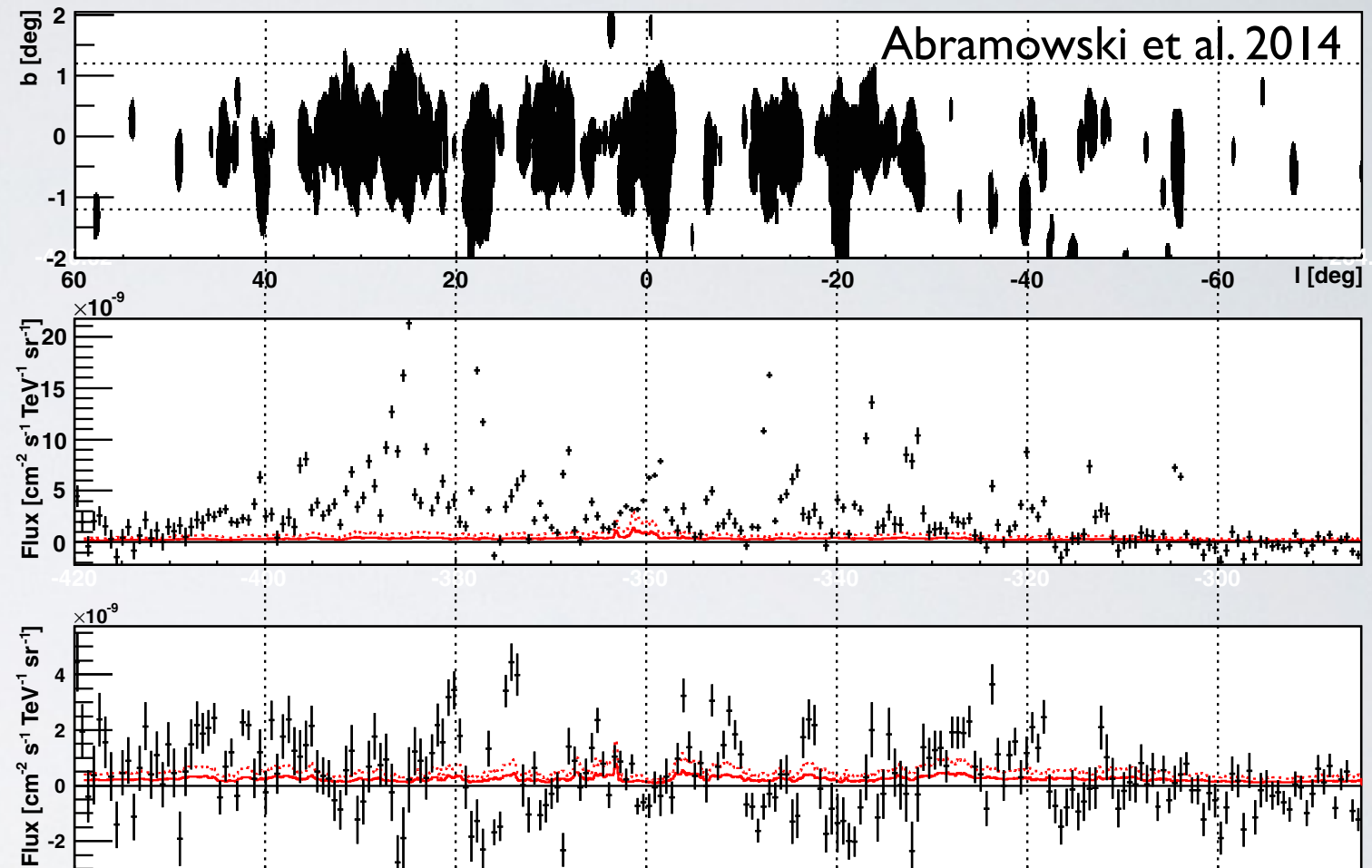
Ackermann et al. ApJ (2014)

Galactic Diffuse Emission



Diffuse contributions:

- Cosmic-ray interactions
 - molecular clouds
 - interstellar gas
- Inverse Compton
- **Unresolved sources**

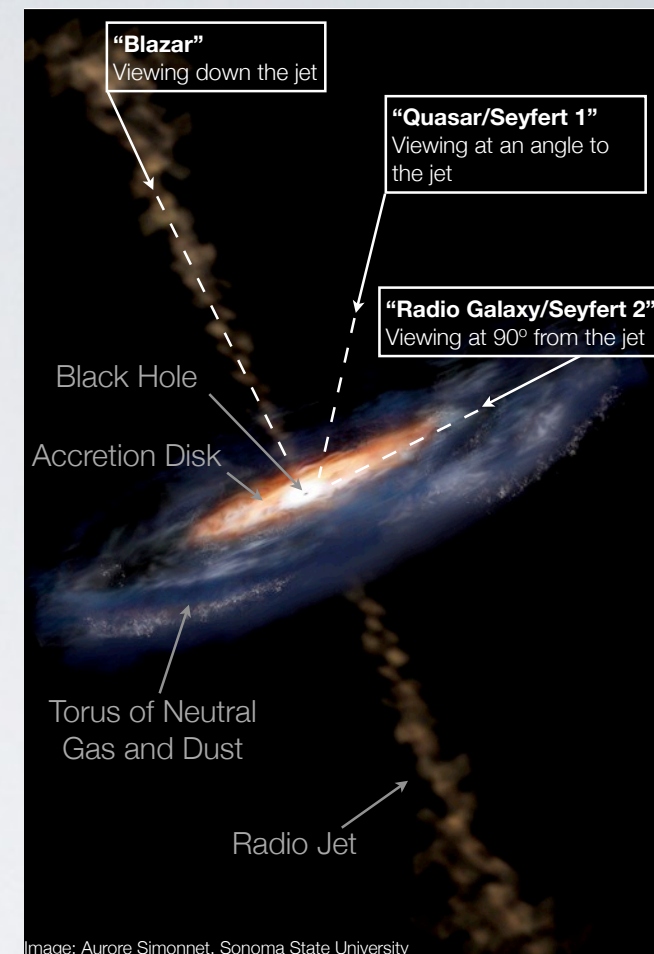


HAWC ICRC 2017

Ongoing work to model extended and multiple sources.

Extragalactic: Active Galactic Nuclei

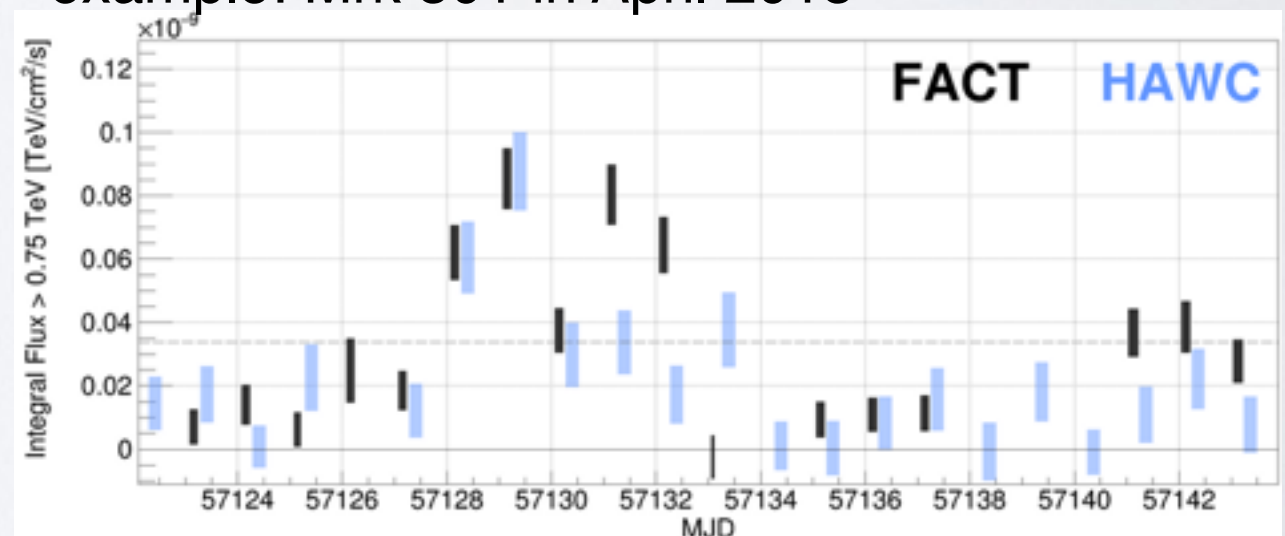
- Majority (>1000) of 3FHL are associated with another galaxy
- ~ 75 TeV AGNs
- Topics:
 - flares
 - extragalactic background light
 - intergalactic magnetic field
- HAWC consistently detects and monitor Mrk 421 and Mrk 501, and presented upper limits to 132 sources selected from 3FHL with $z < 0.3$ [ICRC 2017].



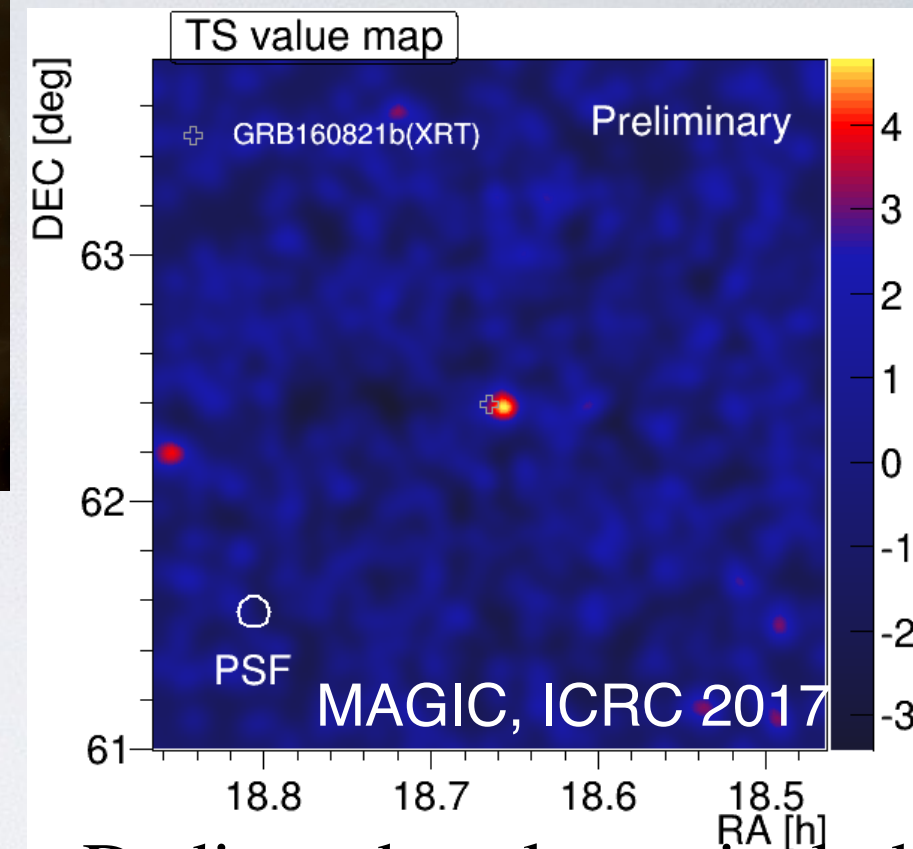
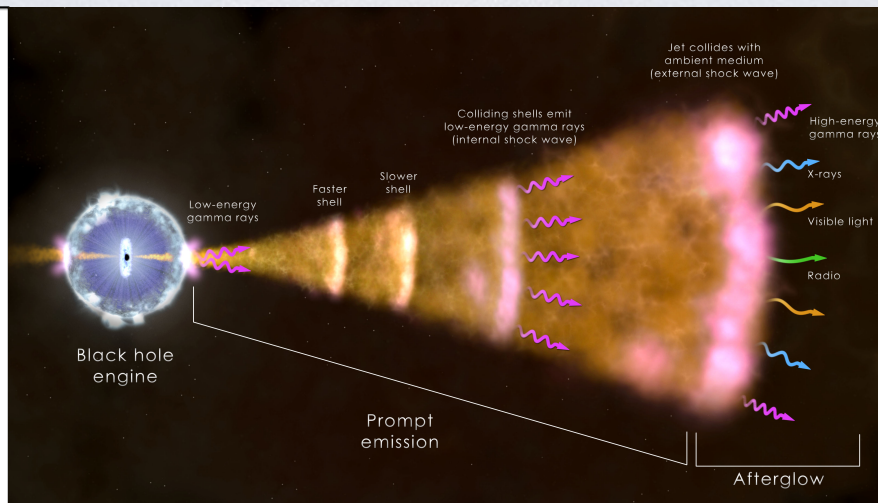
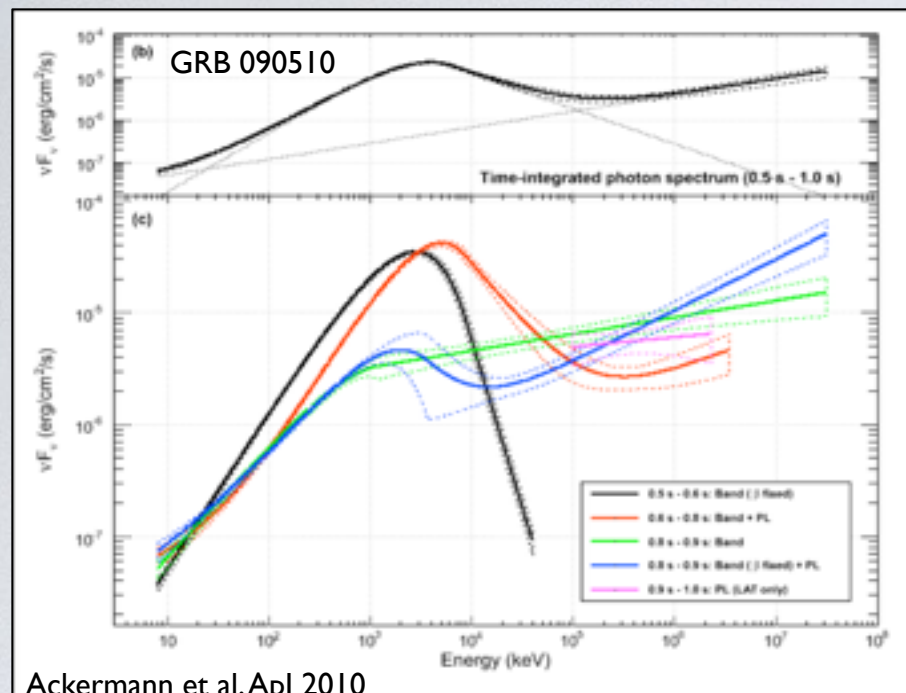
Joint monitoring with FACT
example: Mrk 501 in April 2015

HAWC transient monitoring

- rapid flare monitor: 2min — 10hr
 - fast rising flux from known blazars.
- daily maps: ~ 6 hr
 - flux in every point in all visible sky.



Transient Search: Gamma-Ray Bursts



Talk by S. Dichiara Tue, 17 Oct

HAWC

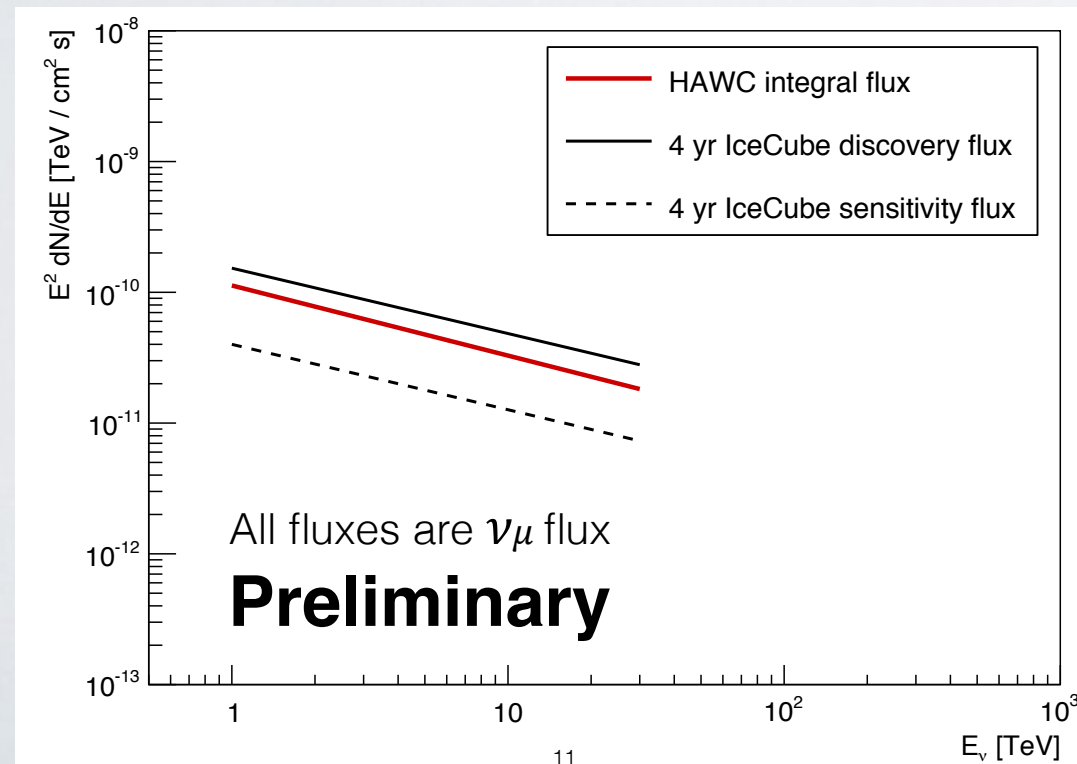
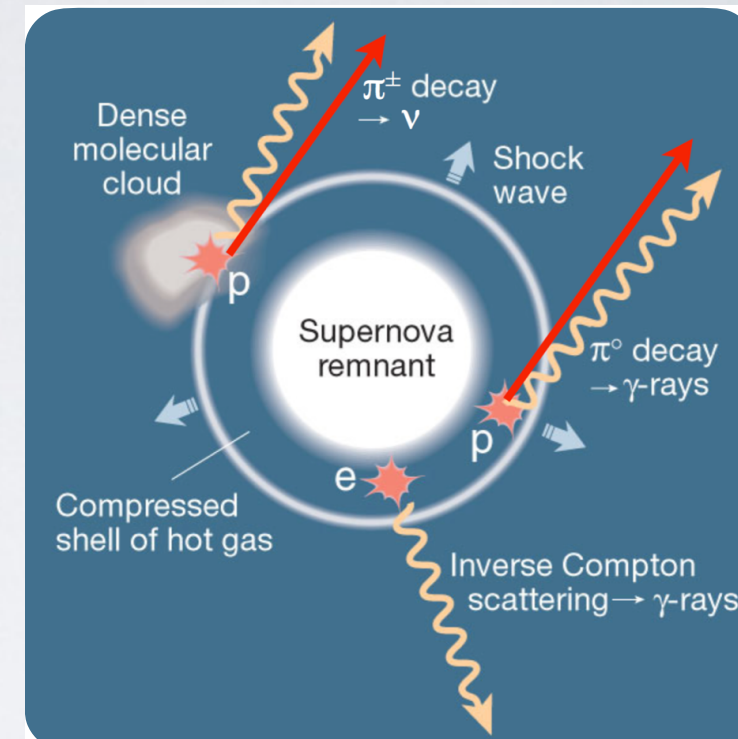
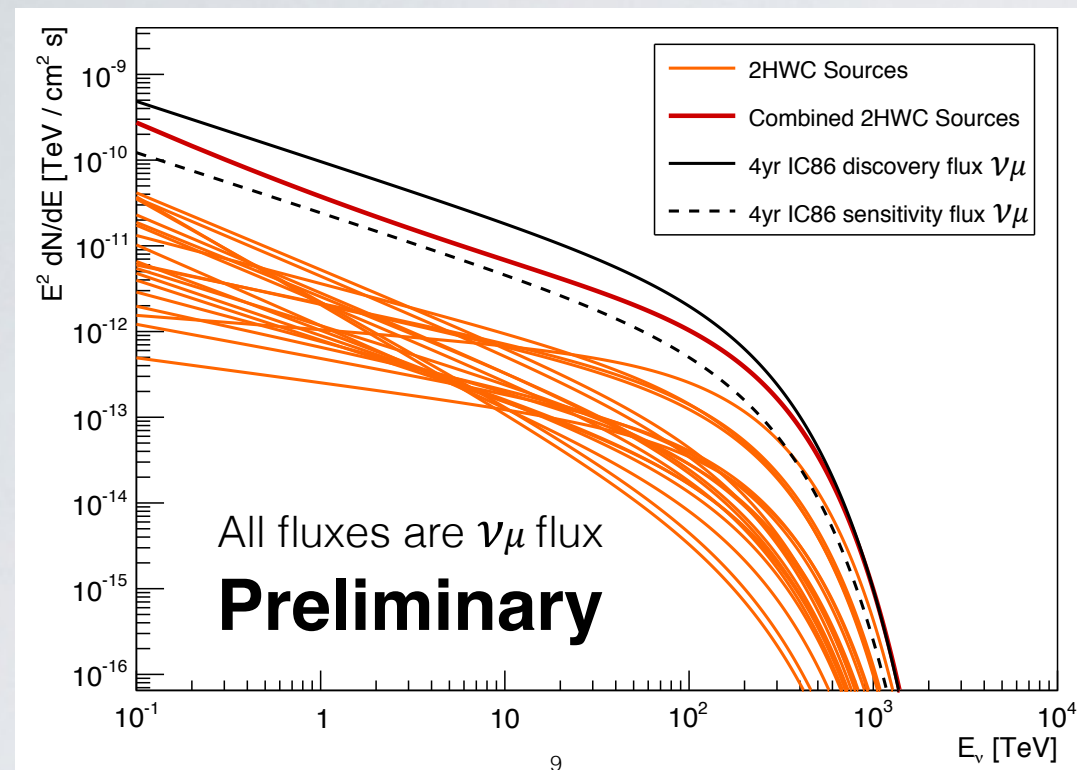
- triggered GRB search: 0.2s — 300s
 - external alerts, searching for temporal and spatial coincidence.
- blind GRB-like search: 0.2s — 10s
 - search entire FOV for burst events.
- ~4 seconds online analysis latency
 - issue fast GRB and transients alerts.

GRB 160821B

- $z=0.16$
- MAGIC observed $\sim 3\sigma$ excess $>500\text{GeV}$
 - exposure up to 4hr after T0.
 - centroid offset from nominal GRB position.

Galactic Origin of IceCube Neutrinos?

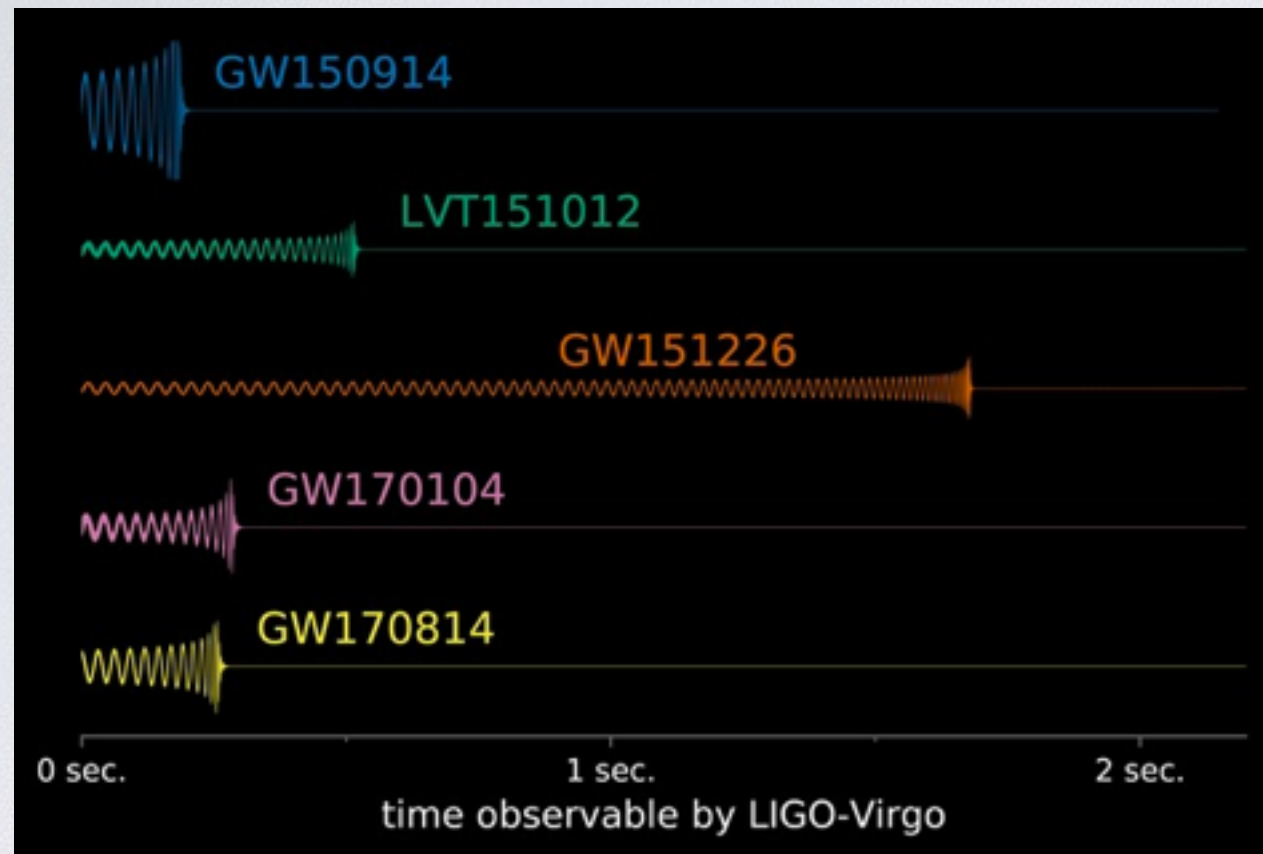
IceCube/HAWC, TeVPA 2017



- PeVatrons producing pionic gamma rays up to 300 TeV and neutrinos up to 150 TeV.
- Stacked analysis using 2HWC sources (excluding PWN) estimate HAWC Galactic plane emission accounts for $\sim 5\%$ of IceCube all-sky flux.
- Template analysis using HAWC flux map of Galactic plane.

LIGO Follow-up

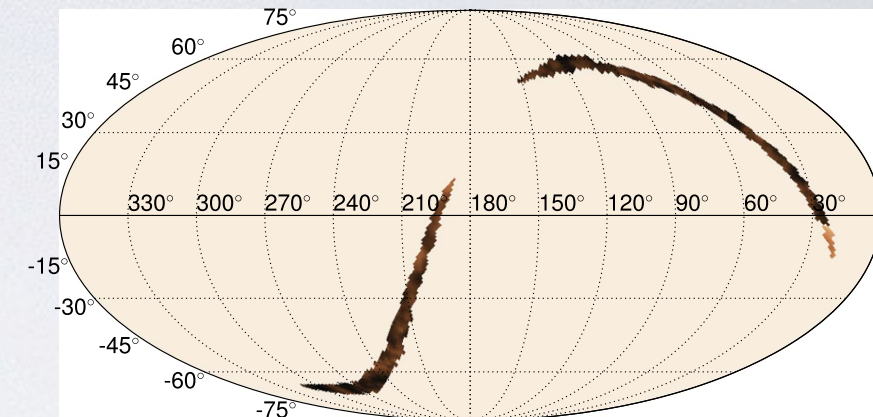
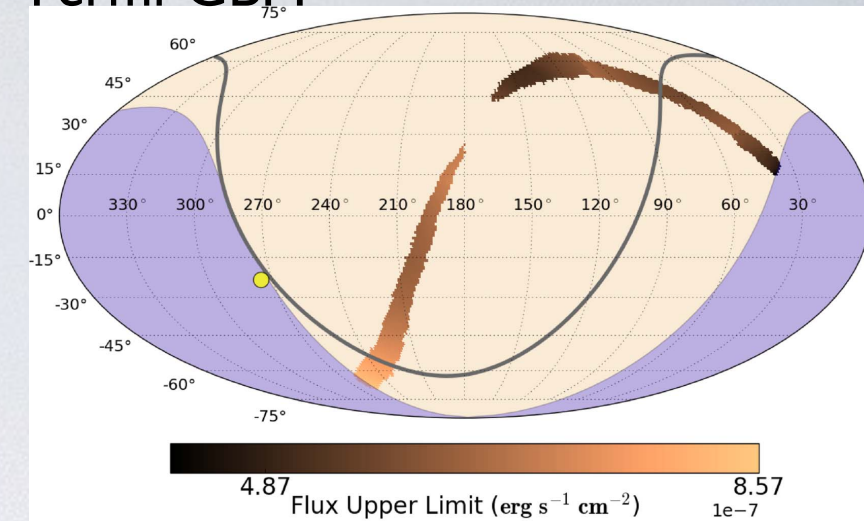
Courtesy Caltech/MIT/LIGO Laboratory



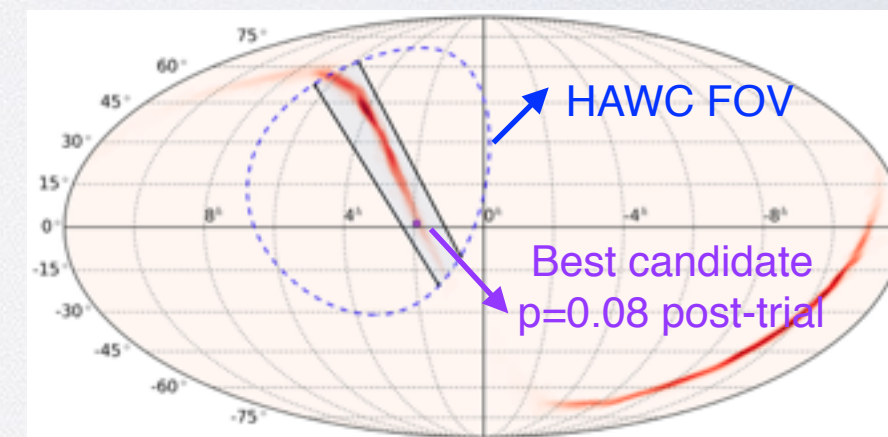
GW151226:

- 2015 Dec 26 03:38:53.6 UTC
- $z=0.09^{+0.03}_{-0.04}$
- $14.2M_{\odot} + 7.5M_{\odot} \Rightarrow 20.8M_{\odot}$

Fermi-GBM



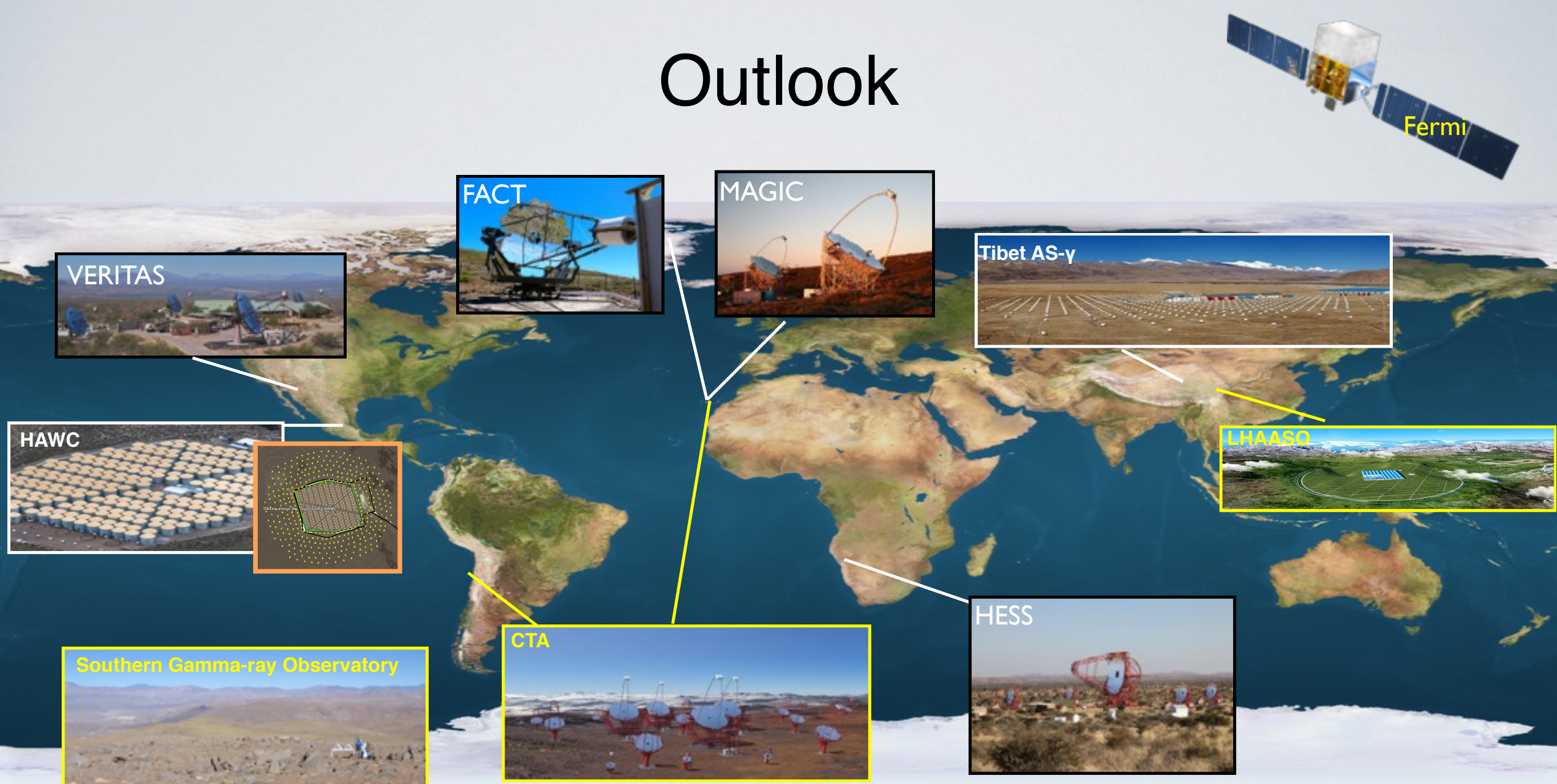
Fermi-LAT



Best candidate 9.98s after LIGO trigger

- post-trial p-value 0.08, consistent with background.

Outlook



- The gamma-ray sky is currently well-monitored with good survey coverage.
- Many instruments from different waveband/messenger (X rays, gamma rays, neutrinos, gravitational waves) available for simultaneous observations.
- Both wide-field and pointing instruments in development and coming online in the next decade.